Comparison of Mechanical Properties of Concretes under Various Curing Regimes

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
January 2020
Gazimağusa, North Cyprus

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ABSTRACT

Concrete is a material that can be affected seriously by different curing regimes. Although, water curing is the preferred one, in practice this cannot always be possible and all types of curing application are actually omitted. This results in reducing of the durability and the strength of concrete which affects the life of structure seriously. Therefore, in this study, various concrete classes that will be designed by two different mix design methods such as BRE (Building Research Establishment) and ACI (American Concrete Institute). Concrete samples produced by two different methods were cured at three different curing conditions until testing age of 7 days and 28 days.

Three curing conditions were decided to be water curing (in curing tank), laboratory in-room curing, and natural outside curing. Concretes produced were tested for fresh mix properties such as slump, Ve-Be, air content, temperature variation of fresh mix, etc. and hardened mix properties after curing such as compression, tension, flexural strength, and non-destructive tests such as hammer and UPV. Concrete classes were designed to be: C16/20, C20/25, C25/30, C35/45, and C40/50. It can be concluded from this study that water and temperature play significant role in strength gain at early age and at long term (28 days) age. Almost for all concrete classes concretes cured in water tank gave strength 10.21% higher than concretes cured in laboratory conditions and 18.9% higher than concretes left outside under natural environmental conditions.

Keywords: Curing, Strength, Mix design, Fresh mix, Non-Destructive, Compressive, Flexural, Splitting, Water, Temperature.

ÖZ

Beton, farklı kür rejimleri tarafından ciddi şekilde etkilenebilecek bir malzemedir. Su kürü tercih edilen doğru bir uygulma olmasına rağmen pratikte her zaman mümkün olmamaktadır ve her türlü kür uygulaması şantiyelerde göz ardı edilebilmektedir. Bundan dolayı da betonun dayanıklılığı ciddi şekilde etkilenmekte olup yapının ömrü azalmaktadır. Kür türü ve süresinin betona olan etkisinin araştırılması için bu projede, iki farklı karışım tasarım yöntemi (BRE-Bina Araştırma Kuruluşu ve ACI-Amerikan Beton Enstitüsü) kullanılarak tasarlanacak olan çeşitli beton sınıflarındaki beton numuneler 7 günde ve 28 günde farklı kür şartlarında bekletildikten sonra deneylere tabii tutulmuşlardır.

Beton numunelerin kürü 3 farklı yöntemle yapılmıştır: Su ile kürleme (kür tankında su içerisinde), laboratuvarda açık ortamda, ve laboratuvar dışarısında açık havada. Üretilen betonlar, çökme, Ve-Be, hava içeriği, taze karışımın sıcaklık değişimi, eğilme dayanımı, beton çekiç dayanımı, ultrason cihazı ile ölçüm, ve basınç mukavameti deneylerine tabii tutulmuşlardır. Tasarlanan beton sınıfları ise C16/20, C20/25, C25/30, C35/45, C40/50 olarak düşünülmüştür. Beton sınıfları seçilirken tümünün de pratikte uygulanabilecek şekilde seçilmesine dikkat edilmiştir. Deney sonuçları elde edildikten sonra ise su küründe bekletilen betonların mukavemetlerinin %10.21 laboratuvar içerisinde bekletilen numunelerden daha yüksek olduğu bulunmuştur. Ayrıca, su küründeki betonların açık havada bekletilen betonların dayanımlarından %18.9 daha yüksek olduğu belirlenmiştir.

Anahtar Kelimeler: Kür, Mukavemet, Karışım tasarımı, Taze beton, Tahribatsız deney, basınç dayanımı, eğilme dayanımı, basmada yarma dayanımı, su, sıcaklık.

ACKNOWLEDGEMENT

I want to appreciate for the effort that Prof. Dr. Özgür Eren has done for me to fulfil any steps for this study. I want to thank the chair of the civil engineering department for preparing the conditions in order to proceed this study. also I want to appreciate the laboratory staff of material of construction who helped me with the full potential for doing this study by the precise procedure.

This study is dedicated to my lovely family especially my mother who always be my side in my whole life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BRE	Building Research Establishment (UK Dep of Environment)
CA	Coarse Aggregate
FA	Fine Aggregate
fc	Compressive Strength
ff	Flexural Strength
fs	Splitting Tensile Strength
SSD	Saturated-Surface-Dry
UPV	Ultrasonic Pulse Velocity
W/C	Water to Cement ratio

Chapter 1

INTRODUCTION

1.1 Overview of Study

An essential part of in the production of high-quality concrete is proper curing of the concrete. This is highly important in order to achieve expected moisture and temperature levels that will improve cement hydration and concrete microstructure. It is well known that concrete strength is seriously influenced by curing regimes (Shabarish Patil, Rajat Vaidya, Vineethraj Math 2016).

Nowadays, overall durability and high level of strength are more common and seen in high performance concrete (S P Shah, S H Ahmad et al. 2011).

The strategic placing and composition of concrete is required for curing, this strongly relates to some of the concrete's properties such as the concretes strength, rate and degree of hydration. Although the temperature conditions and water content of the concrete mixture are at the adequate amount, and cement hydration continues, the cement's level of hydration is at a decreasing rate.

As stated before, in order to achieve durability, one of the most important elements for strength is curing. Concrete is generally cured in a water tank, at the specified temperature. Generally, curing guaranties that the water amount, needed for the mix, is available for cement hydration (Al-Gahtani AS et al. 2010).

Curing has a significant influence on the properties of hardened concrete, such as strength, permeability, abrasion resistance, and volume stability, resistance to freezing and thawing, and deicing chemical. The hydration of cement virtually ceases when the relative humidity (R.Preetha, G.V.V.S.R Kishore, C.Sundaramurthy,C.Sivathanu Pillai, A.K.Laharia et al. 2014).

1.2 Scope and Objectives

In this study, two different mix design methods, which are; Building Research Establishment (BRE) and American Concrete Institute (ACI) were used and ASTM standards in order to design, cast and cure the concrete samples in three different curing condition were followed. The curing conditions that the concretes tested are; in a water tank, in the Laboratory (Materials of Construction, EMU) and Outside in open air for 28 days. The samples from all conditions were then tested for fresh and hardened mixes. The fresh mixes being tested for were; Slump, Ve-Be and Air content and all tests were carried out using ASTM standards. The hardened concrete tests include compressive strength, Schmidt Hammer, UPV, flexural strength and splitting tensile strength.

The aim of this research is to find elements or parameters that will affect the hardened tests results. The main purpose of our ongoing study is to monitor the effects of various curing regimes for concrete on different properties, such as the strength of various concrete classes and then analysis of the behavior of the samples in the curing conditions and compare these regimes result with each other and discuss all the achievements that are affected by the curing regimes and/or elements.

1.3 Thesis Outline

In chapter two, The Literature review, the experiment of concrete curing in general and the specific various curing regimes are used in this study. The advantages and effect curing has on the concrete’s strength will also be discussed.

In chapter three, Methodology, the tests that were conducted and research is discussed. In chapter four, Results and Discussion, all results and outcomes are given, compared and summarized. The above mentioned are all based on scientific relation, equations and basis. Additionally, a more detailed explanation to the study and relation to the topic is provided.

The final chapter, the Conclusion, contains the terminations of the jobs that are carried out and relative to this research.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Due to its good resistance to compressive strength and its durability, concrete is the most popular construction material in today’s era. In order to improve durability and surface hardness, and to decrease permeability, the curing process must be done properly. Additionally, a deep understanding of the materials workability is required in order to conceive a mix (Shikha Tyagi, et al. 2017). One of the first barriers faced during this process is the vaporization. While samples are kept in an open space, the water evaporates freely thus, decreasing the moisture necessary for effective hydration to occur, especially in the top layer. In order to have effective hydration, extra water is to be added continuously in order to compensate for the moister loss through evaporation. For this reason, preventive measures must be taken in order to avoid evaporation in the first place, or systematically cancel its effects. Improper knowledge of proper curing at construction sites has been a topic of discussion for a very long time (Shikha Tyagi, et al. 2017).

Curing has a significant influence on the properties of hardened concrete, such as strength, permeability, abrasion resistance, and volume stability, resistance to freezing and thawing, and deicing chemical. The hydration of cement virtually ceases when the temperature and relative humidity within capillaries drops below 80%. The concrete specimens lose moisture through evaporation and become dry in absence of a proper curing. The evaporation decreases the relative humidity and thereby retards the hydration of cement. In severe cases, when hydration is eventually stopped, sufficient calcium silicate hydrate cannot develop from the reaction of cement compounds and water. Calcium silicate hydrate is the major strength providing reaction product of cement hydration. Without adequate calcium silicate hydrate, the development of dense microstructure and refined pore structure is interrupted. A more continuous pore structure may be formed in cover concrete, since it is very sensitive to drying. The continuous pore structure formed may allow the ingress of deleterious agents, and thus would cause various durability problems. Moreover, the drying of concrete surfaces results in shrinkage cracks that may aggravate the durability problems. It is evident that an efficient curing is inevitable to prevent the moisture movement from concrete surface. The movement of water from the concrete soon after placing depends on the temperature and relative humidity of the ambient air and the wind velocity over the surface of the concrete. These are the major factors that decide the method and curing time of concrete. The temperature during curing also controls the rate of progress of the reaction of hydration and consequently affects the development of strength of concrete; hence the strength of concrete is a function of time interval and temperature (R.Preetha, G.V.V.S.R Kishore, C.Sundaramurthy,C.Sivathanu Pillai, A.K.Laharia, et al. 2014).

2.2 Curing Techniques

General properties are specified by the curing techniques. As stated before, the development of hardened concrete properties, like strength, rely on the hydration of cement. By extension, proper curing must be carried out with a consistently satisfactory level of moisture content, as well as, a stable and convenient temperature.

These levels must be carried out throughout the early stages in order to obtain a result with the desired properties (Sharon Huo X & Wong Ling Ung et al. 2006).

There are a variety of curing methods available, these methods consist of; wet burlap, liquid membrane-forming compounds, insulating blanket, and water spray. In the production of high-quality concrete, proper curing is highly important mainly because of the great surface-area-to-volume ratio, i.e. canal lining or concrete pavement. In order to achieve satisfactory moisture and temperature conditions, one must give great importance to proper curing as it is what leads to proper cement hydration and microstructure development (Shab rish Patil, Rajat Vaidya & Vineet raj Math 2016).

2.3 Workability of Concrete

In order to measure the workability of concrete, the slump test and Ve-Be test are used. By definition, the workability of concrete is the ease of which concrete can be mixed, transported, placed and finished without segregation. The slump test is used extensively at the site. A frustum of a cone, 305 mm high, is used as a mold for the slump test and is conducted per ASTM C 143/C143M-15. After the cone is filled, it is lifted in a slow manner, allowing the unsupported concrete to slump. The decrease in the height of the concrete is called “slump” (Rafat Siddique, Jamal Khatib, and Inderpreet Kaur et al. 2008).

2.4 Composite Cement

Blended cements with more than one blending material are called composite cements. For instance:

Clinker + fly ash + blast furnace slag

Clinker + fly ash + limestone powder

Clinker + blast furnace slag + limestone

Composite cements with fly ash additive can be used to produce concretes for special application. They are suitable for producing alkaline and sulfate corrosion-resistant concrete. Use of fly ash-slag mix allows optimization of the main characteristics of cement clinker and reduction of CO_2 emissions due to a greater cement/clinker ratio. In the future, emitting CO_2 may attract penalties. Therefore, clinker will be increasingly replaced by materials like fly ash, slag, limestone powder, natural pozzolanas, etc. The European Cement Standard EN 197-1 uses Portland Composite Cement as a generic term for the entire Group of CEM II cements. They include CEM II-S Portland slag cements. slag cement has been reported to improve workability, increase cohesiveness, and reduce water demand, the angular and irregular slag cement particles do not benefit as much from the ball-bearing effect that was described for the spherical fly ash particles. Portland composite cements CEM-II M made with granulated slag and limestone have been primarily used so far for industrial purposes (S.P. Deolalkar et al. 2016).

2.5 Compressive Strength

Compressive strength of concrete is one of the most important and useful properties. By design, concrete is used to resist compressive stresses. The concretes compressive strength is then measured to estimate the tensile strength or shear strength, two of which are of primary important. The current trend is to use the compressive strength as a mean of measuring other properties of cured concrete (M.S. Shety et al. 2006).

2.6 Splitting Tensile Strength

In order to evaluate the occurrence of cracks in concrete, the tensile strength and tensile strain capacity of the concrete is used. The tensile strain capacity is defined as the maximum tensile strain that concrete can withstand, without a continuous crack formation. It is easier and more convenient to use the tensile strength capacity in evaluating cracking (ACI Committee 207 et al. 2007).

Tensile strength is important for plain concrete structures such as dam under earthquake excitations. Other structures for example pavement slabs and airfield runways, which are designed based on bending strength, are subjected to tensile stresses. Therefore, in the design of these structures, tensile strength is more important than compressive strength. Ideally, the splitting tensile strength is measured directly on concrete samples under uniform stresses. However, this is not always easy from an experimental point of view. To avoid the demanding and time-consuming direct measurements of the splitting tensile strength, engineers and researchers have tried to predict the splitting tensile using theoretical and empirical approaches based on compressive strength. Generally, tensile strength of concrete was often assumed proportional to the square root of its compressive strength (Kezhen Yan, Hongbing Xu, Guanghui Shen, and Pei Liu et al. 2013).

The compressive and tensile strength of concrete are important design parameters in civil engineering. The splitting tensile and flexural test has been reported as two indirect measure of the tensile strength of cement-based materials. It has been used widely in practice due to its testing ease, simplicity of specimen preparation, and possible field applications. The experimental data also show that the ratio between compressive strength and indirect tensile strength of cement mortar is not constant, but is porosity dependent. The ratio decreases with increase porosity values of cement mortar (Xudong Chen, Shengxing Wu, Jikai Zhou, et al.2013).

2.7 Flexural Strength

The flexural strength directly affects the cracking behavior of a concrete structure and its deflection. In turn, the flexural strength of concrete is proven to be governed by a plethora of factors, notably; the level of stress, its size, the age and the confinement to a concrete flexure member. Research shows interest in what triggers the variability of the flexural strength of the concrete as well as the effect of the curing of concrete members on flexural tensile strength cured under standard testing conditions and cured under site conditions (Ahmed, Mallick and Abul Hasan 2016).

Information about strength properties of a material from which a load-bearing component is made is required by an engineer to complete the theoretical stress analysis of the component. Flexural and tensile strengths are among some of the important properties to be considered. It has been argued that the flexural strength property of concrete is important particularly when the concrete structure has no steel reinforcement. This appears to be also true for tensile strength property of concrete (Joseph. O. Ukpata and Maurice. E. Ephraim, et al 2012).

2.8 Ultrasonic Pulse Velocity

This test uses the measurement of the speed of waves made by a converter passing into concrete, it is known as UPV. The usage of UPV has been conducted throughout decades as a nondestructive test for concrete quality. The general concept works by measuring the velocity or transit time of an ultrasonic pulse through the concrete, in order to assess the characteristics of the concrete studied (IS 13311 (Part I) et al. 1992).

In order to investigate reinforced concrete structures, non-destructive test (NDT) is being developed to assess specific damage. There were a lot of linear ultrasonic testing procedures in concrete. Linear ultrasonic test using ultrasonic pulse velocity (UPV). In ultrasonic test, load pattern and aggregate size should be considered since it greatly influences non-destructive test results. Linear application of UPV in concrete allows investigation of its damage state to check whether the compressive strength of concrete is consistent with given references (Jason Maximino Co Ongpeng et al. 2017).

Some work in previous literature made use of the ultrasonic pulse velocity (UPV) of concrete to predict compressive strength. Pulse velocity is influenced by many variables such as mixture proportions, aggregate type, age of concrete, moisture content, and others. The factors significantly affecting the concrete strength might have little influence on UPV. As a result, a strength estimate made with the pulse velocity method is not a broad spectrum technique. Therefore, the relations derived can be used for structures made with same materials at any time during its service period (N. V. Mahure,. G. K. Vijh, Pankaj Sharma, N. Sivakumar, Murari Ratnam et al 2011).

2.9 Schmidt Hammer

The Schmidt Rebound Hammer (SRH), also known as impact hammer is a popular way used in order to assess strength of concrete. It relies on the surface rebound hardness and its relationship with compressive strength.

To determine the strength of concrete in existing structures, samples are usually taken from the structures and brought to laboratories where they are loaded to failure to obtain actual compressive strength. This procedure is the most accurate way but it requires considerable time and expenses. In order to assess in-site concrete strength in a faster manner, non-destructive testing techniques have been developed and adopted. These techniques estimate the strength of existing structures by measuring some concrete properties other than its strength, and then relate these properties to strength or other mechanical properties of concrete. Among the many available non-destructive testing techniques, the most widely employed is the one using a device called the rebound hammer, also known as the Schmidt Hammer, due to the advantage that the device is portable, less expensive and easy to use. The device uses a spring and measures the hardness of concrete surface using the rebound principle. The aim of rebound hammer tests of concrete is usually to find a relationship between surface hardness and compressive strength within an acceptable error (Kristine Sanchez, and Nathaniel Tarranza et al. 2014).

Schmidt Hammer test method has been used as a non-destructive test. The Schmidt Hammer method could only be used as a reliable instrument to calculate the compressive strength, if the required calibrations are performed. Schmidt Hammer test results can be influenced by many factors; such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and curing type. Therefore, the correction factors have to be used to allow this effect for existing concrete. Schmidt Hammer rebound tests can be used to estimate the strength of concrete with calibration curves to reduce the number of cores taken from the structures (Ferhat Aydin, Mehmet Saribiyik, et al. 2010).

During construction or usage, however, there may arise a need to determine or verify the properties of the concrete. This is why accurate diagnostics of concrete elements or whole structures are essential. Non-destructive testing methods are often used for this purpose. Besides the ultrasonic pulse velocity test, the rebound hammer test is a popular method, because it is easy to use and is practically non-destructive. There are two basic ways of using it to test the concrete. First, to diagnose older structures with the primary purposes of classing the concrete. Second, to assess the quality of new concrete structures with a smooth surface.

Its primary purpose has always been to detect the quality of new concrete elements or structures. The general relationship between hardness and compressive strength were adjusted for this purpose, have been created by the manufacturers and then carried over to technical standards (Dalibor Kocab, Petr Misak and Petr Cikle, et al. 2019).

Chapter 3

METHODOLOGY

3.1 Introduction

In this study ten mixes were casted using two different methods, ACI (American Concrete Institute) and BRE (Building Research Establishment) (ACI Recommended Practice 211.1 (2009) and BS EN (2009)). From these methods, five concrete classes were designed; C16/20, C20/25, C25/30, C35/45 and C40/50. All mixes have their own parameters and amount of aggregates that will be discussed further in this research.

In this study, samples were examined for three different main properties;

1- Fresh concrete properties
2- Hardened concrete properties
3- Non-destructive properties

Each of these categories includes different tests that were done on 7-day age and 28-day age specimens, and their different results will be discussed further in this chapter. Each one of these tests will explain the some mechanical characteristics of each concrete classes in ACI and BRE for 7-days (trial tests) and 28-days cured specimens in three different conditions (water tank, open air, in laboratory) as mentioned before.

3.2 Materials

3.2.1 Type of Cement

In this research, in alignment with ASTM C595-17, Portland-Slag Cement (CEM II / B-S 42.5 N) from BEM (Boğaz Endüstri Madencilik Ltd.) was used as the cement component.

3.2.2 Fine Aggregate

The fine aggregate used in this research was crushed fine aggregate passing sieve 4.75-mm and almost completely retained on 75-µm sieve. Aggregate is from crushed limestone Beşparmak Mountains, Cyprus. The experiment standards applied for the sieve analysis test were those in ASTM international standard (ASTM C136M-14 and ASTM C33) by which the gradation of the fine aggregate was determined. Figure 1 and Table 1 illustrate the evaluation of fine aggregate:

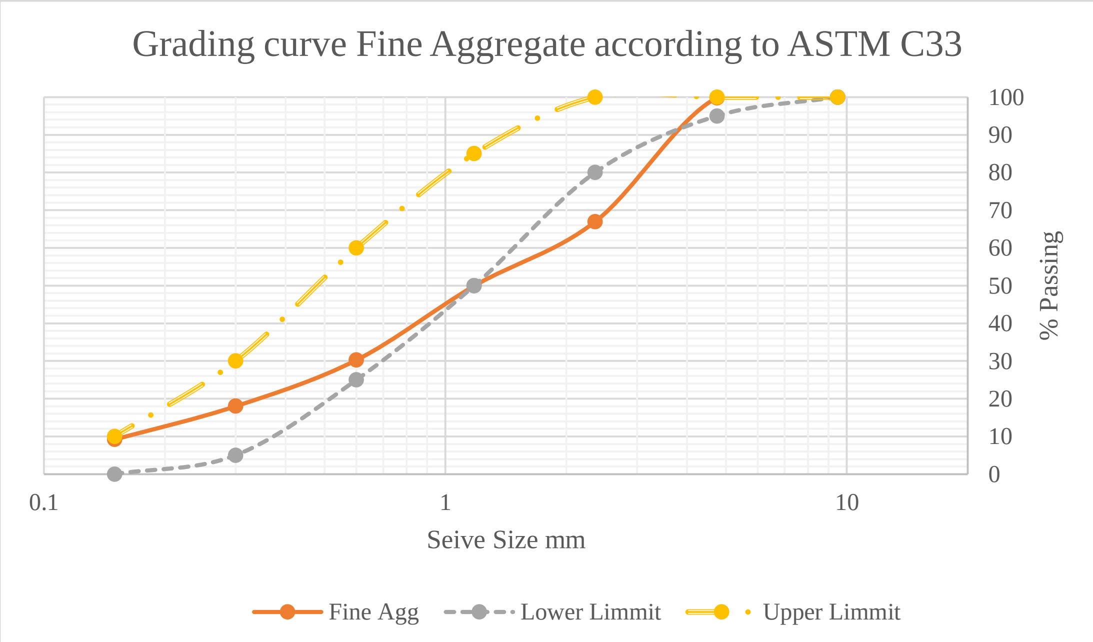


Figure 1: Grading curve of fine aggregate

Table 1: Sieve analysis of crushed limestone fine aggregate

sample weight = 1162 gr					
Sieve (mm)	Mass Retained(gr)	% Retained	Cumulative % Retained	Cumulative% Passing	ASTM C33 limits
9.5	0	0	0	100	100
4.75	2.00	0.17	0.17	85.48	95-100
2.36	381.00	32.87	33.05	66.95	80-100
1.18	197.00	17.00	50.05	49.96	50-85
0.6	228.00	19.67	69.72	30.28	25-60
0.3	142.00	12.25	81.97	18.03	5-30
0.15	102.00	8.80	90.77	9.23	0-10
pan	107.00	9.23	100.00	0.00	
total	1159	100			

3.2.3 Coarse Aggregate

The coarse aggregate used in this research was crushed limestone from Beşparmak Mountains, Cyprus which consisted of aggregate with maximum sizes 10 mm and 20 mm. Using ASTM C136-14 sieve analysis, the gradation of coarse aggregate was found in all dimensions, complying with ASTM C33M-16. Figure 2 and Table 2 show sieve analysis and grading of the coarse aggregate.

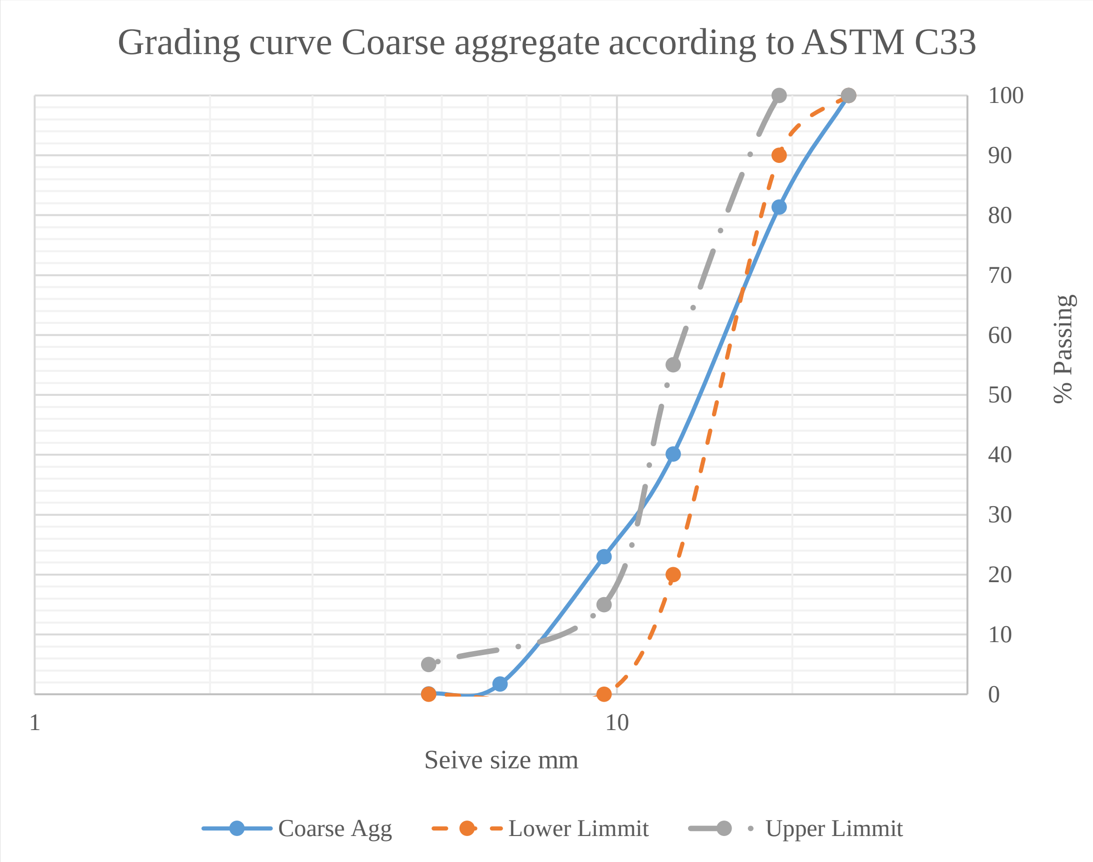


Figure 2: Grading curve of coarse aggregate

Table 2: Sieve analysis of crushed limestone coarse aggregate

Sample weight = 3069 gr					
Sieve (mm)	Mass Retained (gr)	% Retained	Cumulative % Retained	cumulative % Passing	ASTM C33 limits
25	0	0	0	100	95-100
19	571	18.66	18.66	81.34	0
12.5	1261	41.21	59.87	40.13	25-60
9.5	525	17.16	77.03	22.97	0
6.3	650	21.24	98.27	1.73	-
4.75	50	1.63	99.90	0.10	0-10
pan	3	0.10	100.00	0.00	0
total	3060	100			

3.2.4 Water

The mixing water used in the concrete was pure and free of any impurity like oils, acids, alkalis, salts, organic materials or other substances that may threat concrete or steel (ASTM C913-18).

3.3 Mixing Proportions

Mix design BRE and ACI, involve calculating the proportions and amounts of primary materials to be used in order to achieve an appropriate concrete mixture under one standard that is called ASTM for each related test. Each of them has their own progress, tables or figures for determination of the aggregates amount. In this study, three experiments have been done to get the main and essential amounts in order to determine the amount of each class of concretes such as dry rodded unit weight, specific gravity and sieve analysis (which was mentioned before).

3.3.1 Dry Rodded Unit Weight

In order to complete the calculations for the ACI method, in this experiment, the dry-rodded unit weight needs to be determined first. To determine its amount, a bulk with the volume 0.0141 m^3 is taken with the coarse aggregate size of 10 and 20 mm and according the ASTM C138/C138M-17a the test was carried out. The dry-rodded unit weight calculation was carried out using the below formula:

$$\text{Dry Rodded Unit Weight} = (M-m) \div V \quad (1)$$

Which M is full bulk weight, m is empty bulk and V is the bulk volume.

3.3.2 Coarse Aggregate Specific Gravity (SSD)

This test is done according to the ASTM C 127 which is about specific gravity for Coarse aggregate:

$$SSD_{20\ \&\ 10}\ \text{(Saturated-Surface-Dry)} = B/(B-C) \quad (2)$$

In order to adjust the amount of the water for each coarse sizes, Equation 3 below is used:

$$WA_{20\ \&\ 10} = B/(B-A) \tag{3}$$

3.3.3 Fine Aggregate Specific Gravity (SSD)

This test is done according to the ASTM C 128 which is about specific gravity for fine aggregate.

SSD is determined with Equation (4) given below:

$$SSD = S/(B+S-C) \tag{4}$$

In order to adjust the amount of the water for each coarse sizes, Equation (5) below is used:

$$WA = (S-A) / A \tag{5}$$

Tables 3 to 7 show the proportions and amount of each element of five concrete classes in BRE manner.

Table 3: Concrete Mix Design for BRE and ACI of C16/20

BRE						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	450	225	833	289	578	0.5
adjusted m^3	-	229	814	277	575	
ACI						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	188	157	682	240	500	0.83

Table 4: Concrete Mix Design for BRE and ACI of C20/25

BRE						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	511	225	770	270	599	0.44
adjusted m^3	-	228	753	259	569	
ACI						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	277	156	638	240	500	0.56

Table 5: Concrete Mix Design for BRE and ACI of C25/30

BRE						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	563	225	730	286	571	0.4
adjusted m^3	-	229	714	274	569	
ACI						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	270	155	605	240	500	0.57

Table 6: Concrete Mix Design for BRE and ACI of C35/45

BRE						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	662	225	655	278	555	0.34
adjusted m^3	-	226	641	267	553	
ACI						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	321	154	560	240	500	0.47

Table7: Concrete Mix Design for BRE and ACI of C40/50

BRE						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	726	225	612	271	541	0.3
adjusted m^3	-	223	600	260	538	
ACI						
Quantities	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate		W/C Ratio
				10 mm	20 mm	
per m^3	376	153	516	240	500	0.4

3.4 Fresh Concrete Test

3.4.1 Slump Test

In order to assess the workability of concrete through performance, fresh concrete is poured into a special slump test-cone in three layers and compacted with a rod after each layer poured; Thereafter, the cone is lifted gently leaving the concrete subjected to the forces of its weight and then the height difference between the cone and the subsided fresh concrete is measured in terms of millimeter that is actually called slump of the concrete, and the test is known as slump test. It was performed according to ASTM C143/C143M-15 for the target of 100 mm in this research and is popular as a benchmark measure for concrete performance.

3.4.2 Ve-Be Test

The general concept of the Ve-Be test is the usage of a vibrating platform in order to measure the consistency of a stiff to extremely dry concrete mixture. The concrete is placed inside a cylindrical tank with a cone, and then compacted with 25 strokes of a rod in three different stages. This process is carried out before the cone is dismantled in order to allow the concrete to flow into the tank.

Next a rounded plastic plate is placed on the concrete's surface. The slider is then turned on and the time is measured, using a chronometer, until cement's water becomes visible on the surface of the plastic plate. The performance of the concrete is determined at the same time. The Ve-Be test was performed according to ASTM C1170/1170M-14.

3.4.3 Entrapped Air Content Test

As indicated by the name, the air content test is used to define the amount of air present in freshly mixed concrete. However, it is not ideal for measuring the air that might be trapped inside aggregate particles and it also requires determination of aggregate correction factor, therefore it is only applicable to relatively dense aggregate containing concretes.

In order to proceed with the test, a measuring bowl with a dampened interior is placed on a flat leveled surface and then the concrete is poured into it in three equal volumes. Each volume is tamped 25 times, using a special round-ended rod. Special attention was paid to not damaging the container during the rodding stage, at which the bottom layer of the concrete was targeted. After the concrete is consolidated, its top surface is smoothed using a trowel to ensure the integrity of the sample´s volume .

The volume of air content is determined according to ASTM C231/C231M – 17a using the change in volume due to the change of pressure.

3.4.4 Temperature Measurement

In order to measure the freshly mixed concrete's temperature, the thermometer has to be put in a specific way so that its bottom, the sensitive part, is submerged under at least 75 mm [3 in.] of fresh mixed concrete. Next, in order to fill the gaps and voids created by the insertion of the device, and in order to get a more accurate reading, the concrete is gently pressed at the surface, releasing the whole air that may create interference. The device is then left inside, for a minimum duration of two minutes and up to maximum five minutes, before being read and recorded to the 0.5°C [1°C] detail according to ASTM C1064/C1064M – 17.

3.5 Casting and Curing of Concrete Samples

In this study, two different types of concrete were used to create the concrete specimens: Cubic specimens of size 100 mm and beams of size 100 × 100 × 500 mm^3. Prior to pouring the mixture into the molds, the interior surface of the molds were lubricated by a specific oil in order to avoid of any problems in the demolding process before using plastic molds. The fresh concrete is then poured into molds, and then vibrated for a few minutes using the vibrating table and the samples were then placed in moisture room for 24 hours. Afterwards at the due time, all samples were extracted from the mold the following day and were placed in the determined places using three different curing methods: immersed in water tank, preserved in laboratory and preserved outdoor in open space for the following 7-28 days as.

Figure 3: Water Tank curing of specimens

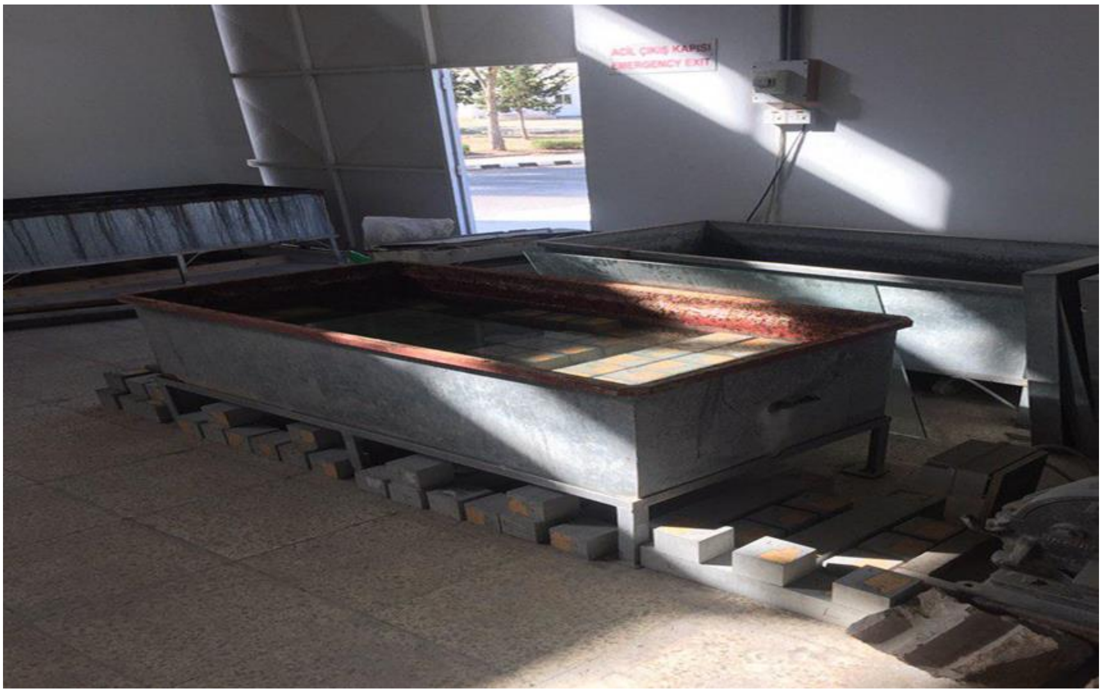


Figure 4: In-Laboratory Environment curing of specimens

Figure 5: Outside (open air) Environment curing of specimens

3.6 Hardened Concrete Tests

3.6.1 Compressive Strength Test

According to ASTM 32 C39/C39M – 17 Standard, the test was conducted using cubic samples of size 100 mm. Three samples of each condition used on each test, so totally, nine samples in each concrete class were used for testing samples for each three different conditions. Test was done to achieve compressive strength targets for each concrete class respectively as follow: 24MPa, 30MPa, 35MPa, 45MPa and 50MPa. Figure 6 and Figure 7 shows before and after the test for compressive strength.


Figure 6: Specimen before compressive strength


Figure 7: Specimen after compressive strength test

3.6.2 Flexural Strength Test

According to ASTM C 26 1609 -2010, the flexural strength test was done at 28 days on three beams with dimensions 100 × 100 × 500 mm^3 in three different curing conditions using flexural testing machine. Figure 8, Figure 9 and Figure 10 show before, during and after the test.

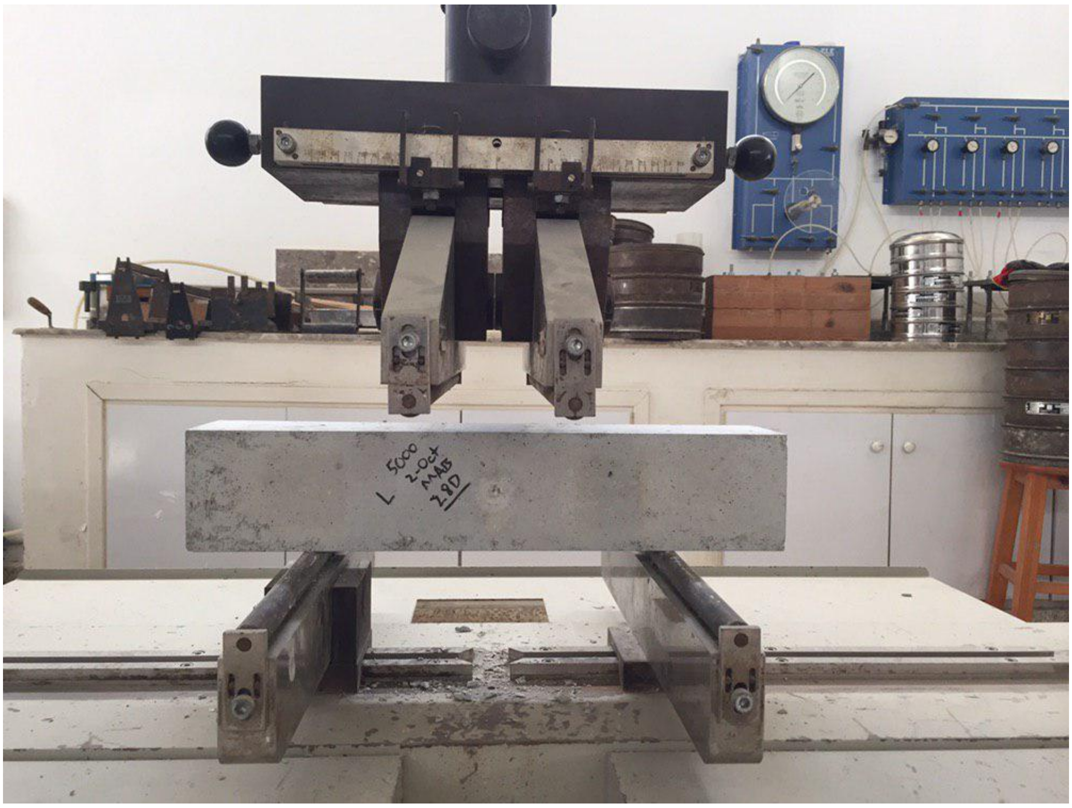


Figure 8: Concrete sample before the flexural strength test

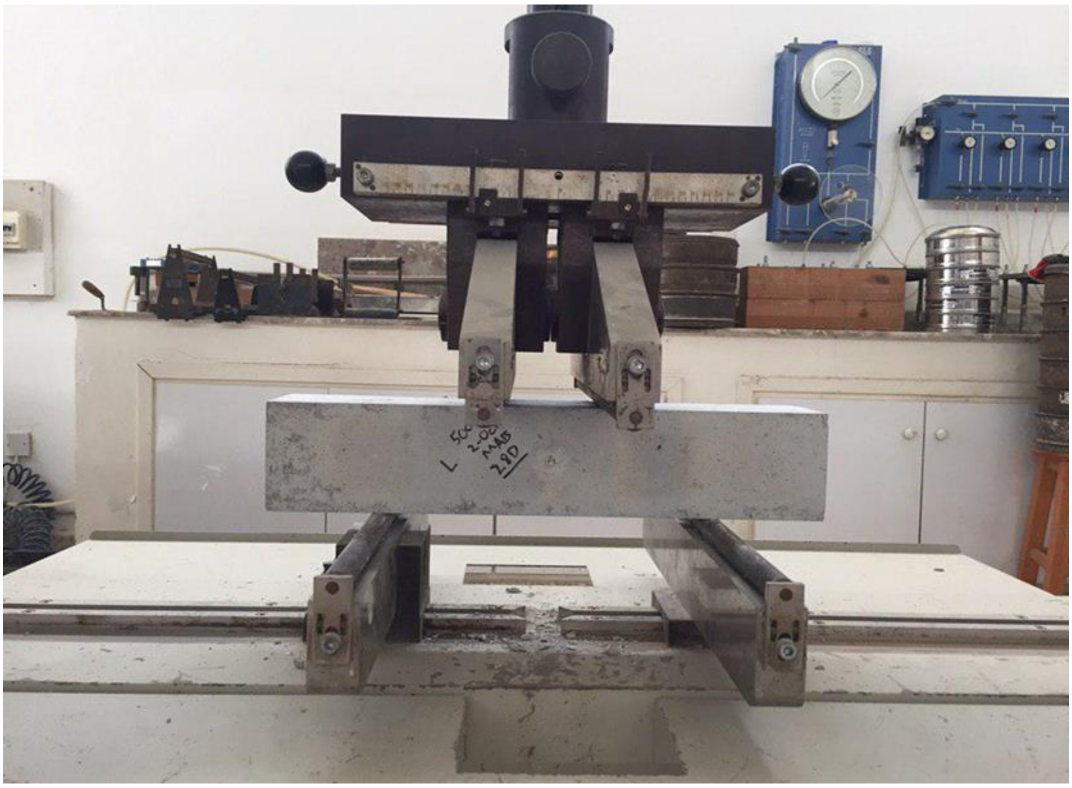


Figure 9: Concrete sample during the flexural strength test

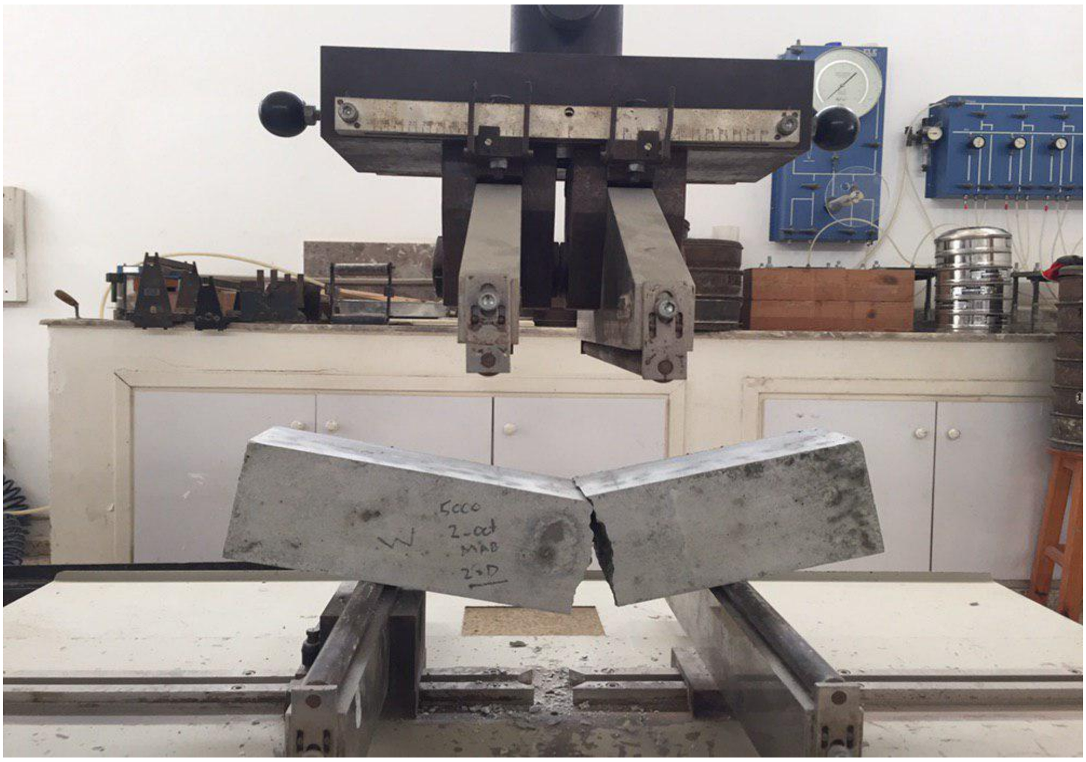


Figure 10: Concrete sample after the flexural strength test

3.6.3 Splitting Tensile Strength Test

Based on ASTM C496/C496M – 11 standards, three cubic concrete specimens of each concrete class in each conditions with dimensions 100×100×100 mm^3 at 28-day age were used. The number of observations were chosen as three to heighten the accuracy of the experiments. Figures 12 and 11 shows the specimen before and after the splitting test was done.

Figure 11: Sample before doing the splitting tensile test

Figure 12: Sample after the splitting tensile test

3.6.4 Ultrasonic Pulse Velocity Test

The aim of this test is to determine the velocity of a longitudinal stress wave according to ASTM C597-16. The pulse velocity V is calculated by dividing L by T as shown in Equation 6:

$$V=L/T \tag{6}$$

Where; V = pulse velocity in m/s, L.= distance between. centers of transducer faces. m, and T = transit time in s.

Figure 13: UPV test on the cubic sample

3.6.5 Schmidt Hammer Test

According to ASTM C805/C805M-18, this test method is applicable to assess the in-place uniformity of concrete, to delineate variations in concrete quality throughout a structure, and to estimate the in-place strength of concrete if a correlation is developed. Before performing the compressive strength test, placement of the hammer, perpendicular to the sample surface, to carry out a hammer test 10 times was required. The units are recorded and at the end. The averages of 10 units were selected as a rebound number. Figure 14 shows all the nine samples of each 100 mm cube tested for rebound number.

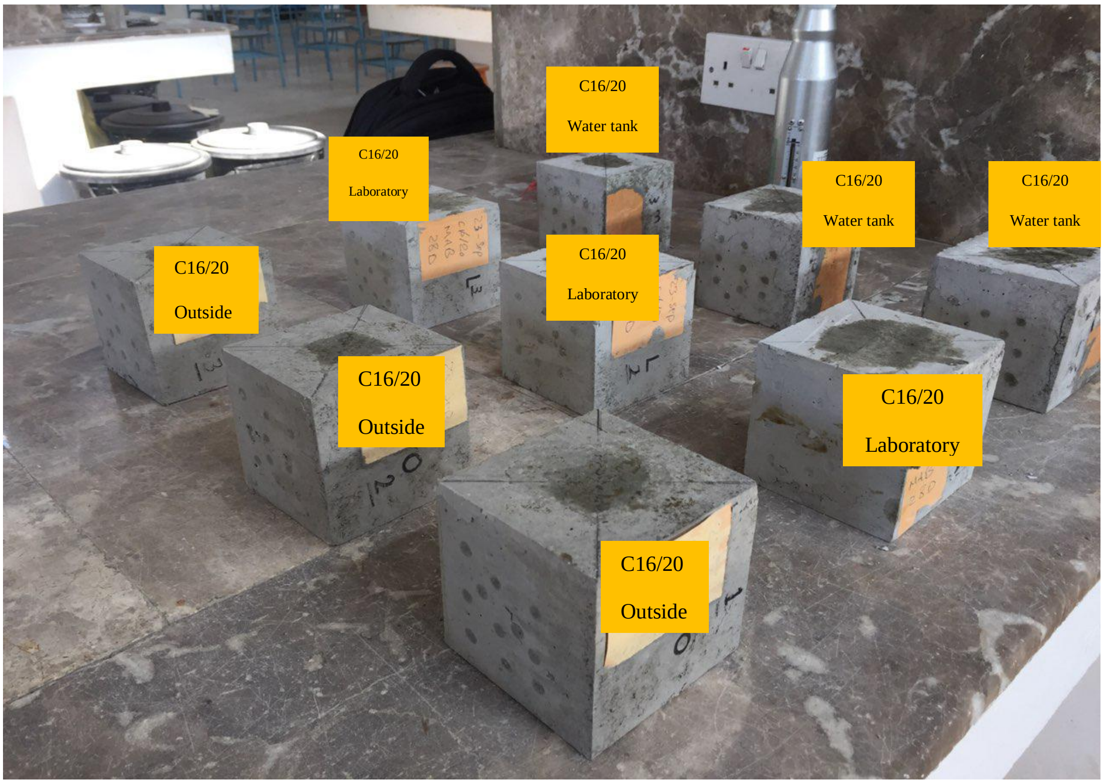


Figure 14: Schmidt hammer test done to all samples of C16/20 concrete class

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this study, the concrete samples used were produced by the two different mix design methods; BRE (Building Research Establishment, UK Department of Environment) and ACI (American Concrete Institute). The samples include 100×100×500 mm^3 beams and three cubes in dimensions 100 mm^3, which were made and kept in the three different curing conditions mentioned before; water tank, in-laboratory and outside.

During this study, two main group of tests were carried out; one group on the fresh concrete and the other group on the hardened concrete samples. The tests on the fresh concrete samples included Slump test, Ve-Be test, concrete temperature test and entrapped air content test. The tests on the hardened concrete samples were; Pundit test, Compressive strength test, Schmidt hammer test, flexural strength test and splitting tensile strength test according the ASTM standards.

4.2 Environmental Factors

4.2.1 Temperature and Humidity Monitoring

One of the influential factors on the test-results of the construction materials, in this experiment, was temperature variation. Temperature monitoring was carried out during this experiment to observe its effects on the properties of concrete samples. Special attention is occurred to this detail as the study was conducted in the last days of summer and the first days of Fall of 2019. Readings of temperature, in Celsius degrees, were 18 times during mornings, and 17 times during evenings along the 28 days curing process in water tank, Laboratory and Outdoor.

Figure 15 shows the average temperature of the samples in each three different curing conditions, at two different times of the day, morning and evening. From the figures it is shown that the minimum and maximum temperatures are corresponding with curing in water tank and outdoor, respectively, both in the mornings and the evenings. The variation of the temperature for the different conditions in the morning and evening are 1.35 and 10.22, respectively. As it is shown in Figure 15, the laboratory condition temperature is 5.52% higher than water tank condition and 0.39% higher than outside curing condition.

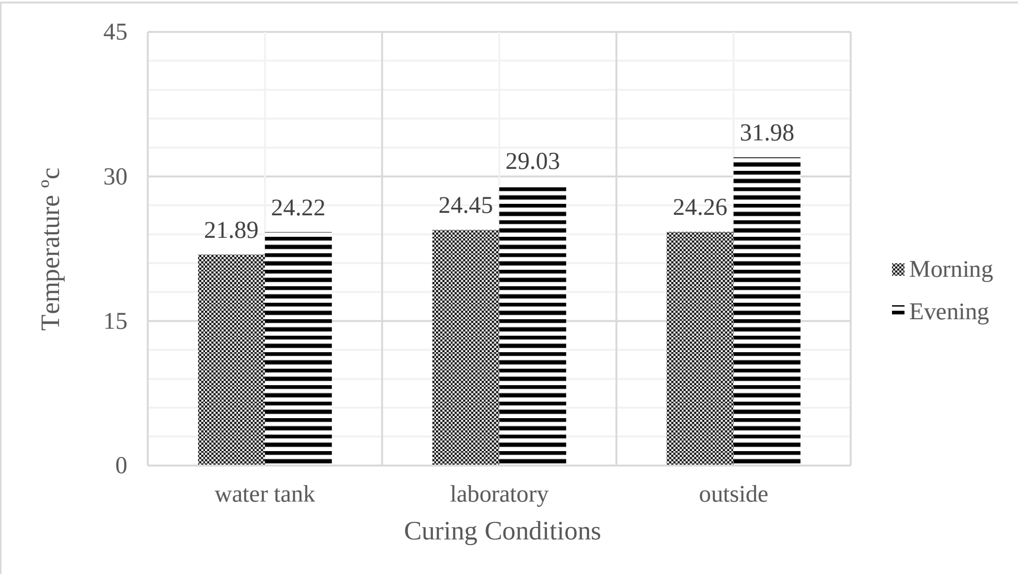


Figure 15: Average temperature at different curing conditions

Another factor that is important during the curing is environmental humidity. Figure 16 shows the relative humidity of the laboratory and outside in which the relative humidity for the outside curing regime is 10.3% more than the laboratory during the evening and during the morning is 13.05% more.

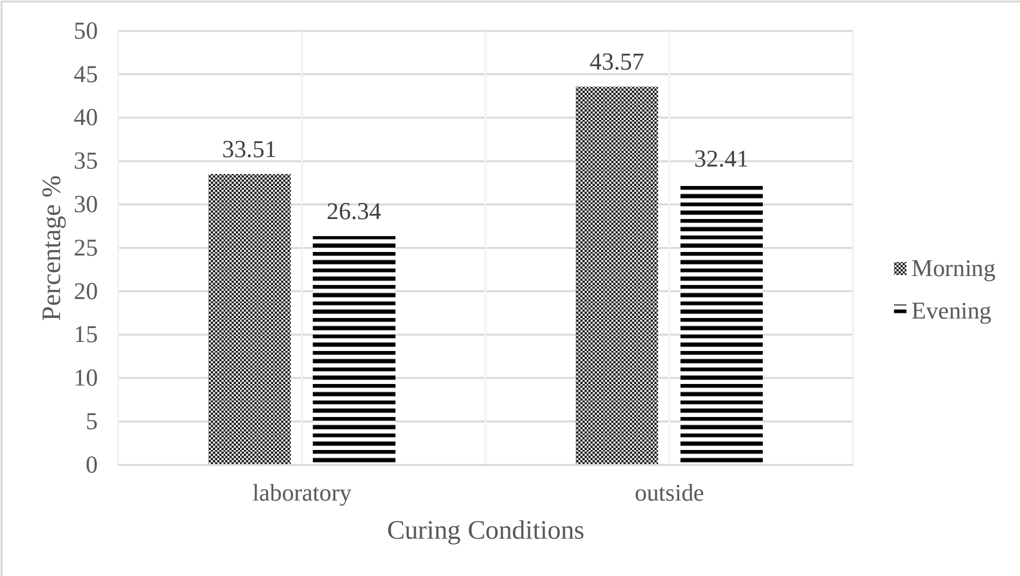


Figure 16: Humidity percentages for the curing conditions in the morning and evening

Although temperature is one of the factors that affects to the strength of the concrete, it is, in actual fact, the changing of the temperature that causes the effect. Throughout this study, the temperature in the water tank is almost always consistent and does not fluctuate very much. The concrete mix's temperature, in-laboratory, rises a little as the temperature of the area changes and the outside (open air) sample experiences a lot more frequent temperature change. This is due to the existence of the sun and, more importantly, the climate changes in the area.

4.3 Fresh Concrete Tests

4.3.1 Slump Test

Figures 17 shows the average slump test results of both BRE and ACI designed samples with the target of 100 mm for each mix design and concrete class. As illustrated in Figure 17, the maximum measured slump for BRE and ACI are respectively 70 and 75 mm in class C16/20 and decreasing by the concrete class differs. The minimum measured slump for BRE and ACI are 30 mm and 25 mm, respectively in class C40/50. Also the variation of slump test for BRE and ACI are individually 166 mm and 351.5mm.

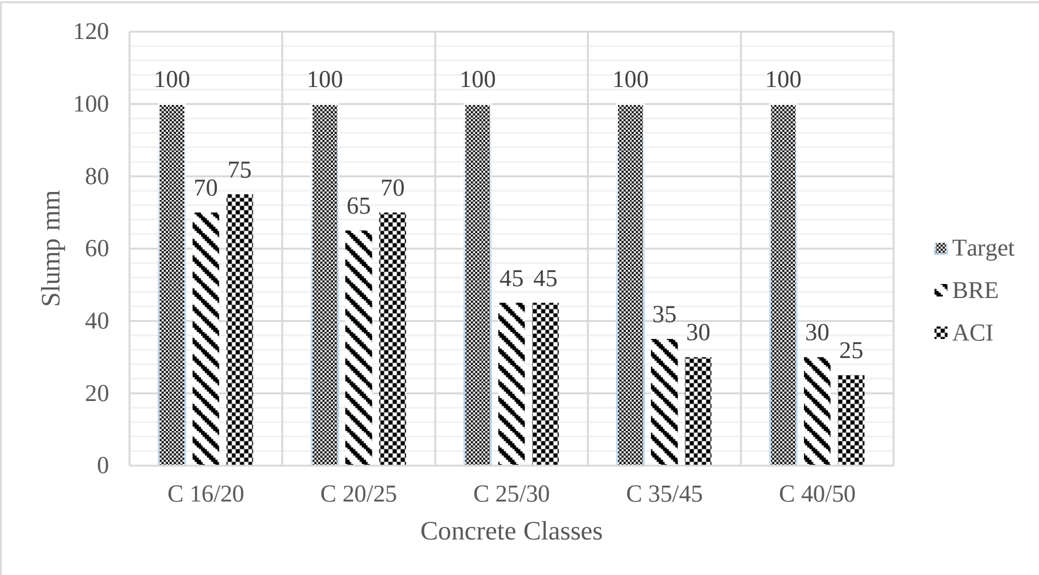


Figure 17: Average Slump test result concretes designed by BRE and ACI methods

As mentioned before in details, the concrete class that gave the highest slump is C16/20, and as the strength of the classes grows, the slump value decreases. From this, it can be concluded that the slump has a direct relationship with the values of water and cement. Additionally, as the W/C ratio decreases, the slump decreases too, in both mix designs, and all of the concrete classes. Figure 17 shows that not only shows the slump decrease, but also the reduction in W/C ratio. In addition, slump test of C40/50 is 33.3% and 48.7 % lower than that of C16/20, in ACI and BRE, respectively. In this study the average of the slump test for the BRE and ACI is 49 mm.

4.3.2 Entrapped Air Content Test

The below Figure 18, illustrates the average entrapped air content value of the fresh concrete samples, in BRE and ACI. It can be concluded, from these results, that the minimum amount for each mix design is 1% and 1.3% in concrete class C16/20 referring to BRE and ACI. It can also be seen that the maximum amount for BRE mixes is 1.65% in C25/30 and in ACI is 1.7% in C40/50. The variation amount also is 0.0704 and 0.0286 in BRE and ACI. In addition, the average of the entrapped air content for BRE and ACI are 1.31 and 1.52 which shows that the average amount of entrapped air content for ACI is 7.42% higher than BRE.

Each concrete class has different values of aggregates. As the strength of the concrete classes increase, the amount of fine and coarse changes so, with reference to the results it can be seen that the minimum and maximum amounts are for C16/20 and C40/50, therefore it is possible to be stated that the aggregate in these classes are different and that the number of pores, in which air will be entrapped, in are different from each other.

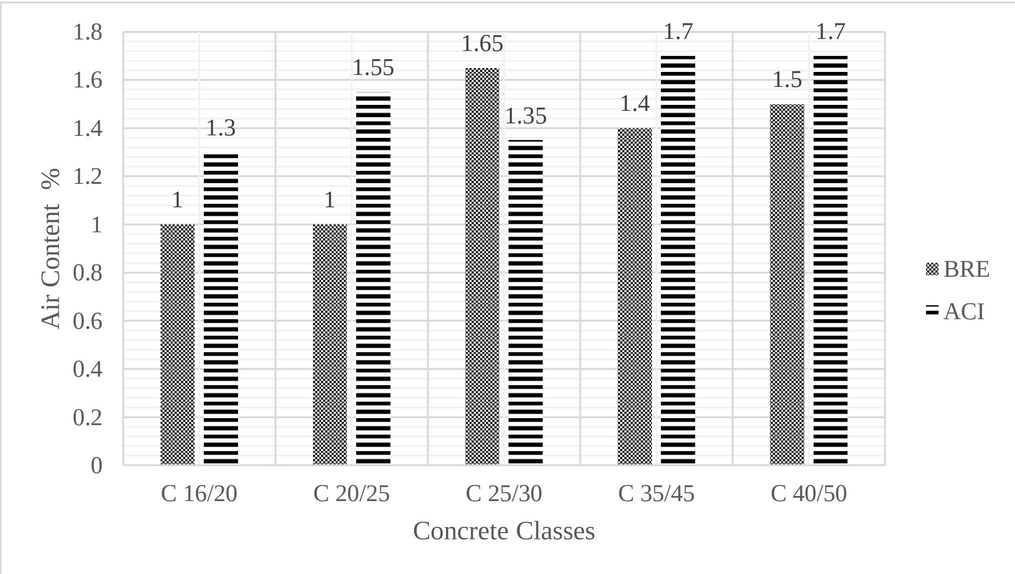


Figure 18: Average entrapped air content percentage of fresh concretes designed by BRE and ACI methods

4.3.3 Ve-Be Test

In this test's results, the samples have ascending changes, in both BRE and ACI (indicated in Figure 19). The average for BRE and ACI are 6.01s and 5.7 which shows that the results for the BRE is 2.64% more than ACI. The variation amount is 4.022

and 5.001 for BRE and ACI. As shown in the figure, the minimum and maximum amount of Ve-Be are for the samples C16/20 and C40/50. These samples are 3.37s and 8.33s in BRE and 3.31 and 9.29s in ACI for 7 and 28 days curing. Moreover, in C16/20 it is 42.5 % less than in C40/50 for BRE samples and is 47.46 % less than for ACI samples.

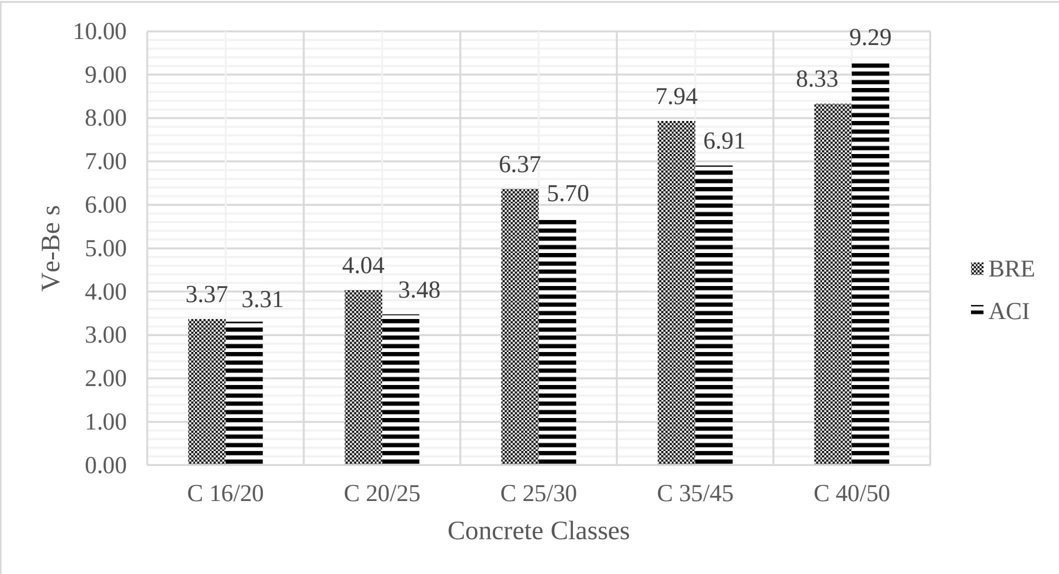


Figure 19: Average Ve-Be time for concretes designed by BRE and ACI

As it is shown, in Figure 20 and 21, the relationship is inverse in five different concrete classes. As the amount of slump decreases, the amount of Ve-Be will increase, this then reveals an inverse relationship between slump and Ve-Be. In the below stated figure, this comparison is illustrated for 7 and 28 days curing and is determined in both BRE and ACI.

As mentioned before, slump and Ve-Be values are strongly related to the water and cement content, or simply the water to cement ratio of the concrete sample. Changes in water and/or cement content (or W/C ratio) will cause either an increase or decrease in slump and Ve-Be results. For example, when experiencing a decrease in slump levels (therefore an increase in Ve-Be), the amount of whole W/C ratio should be decreased and by this decreasing means, having a decreasing in water content and increasing in cement content of the sample.

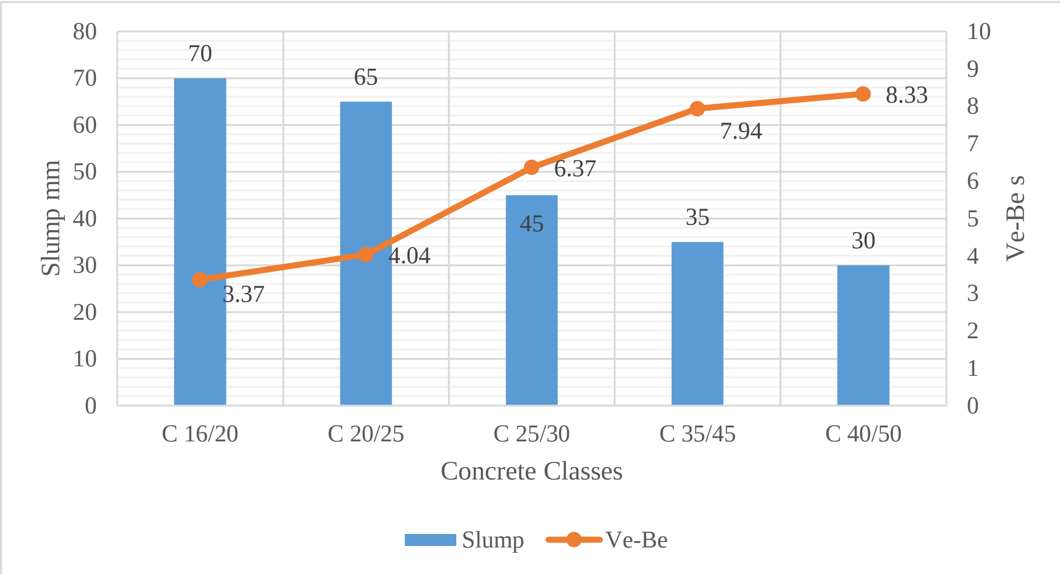


Figure 20: Average Slump versus Ve-Be time for concretes designed by BRE method

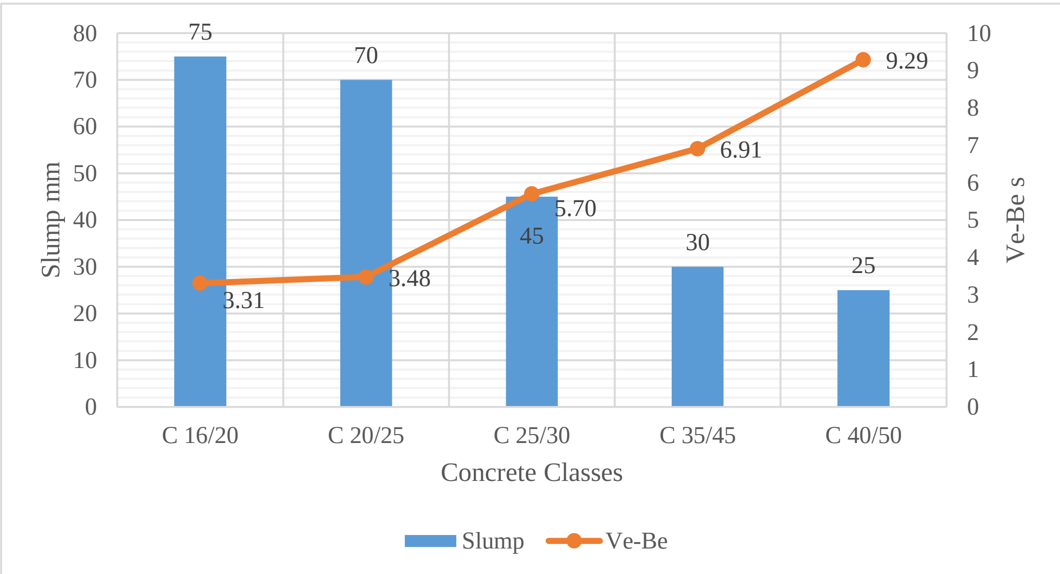


Figure 21: Average Slump versus Ve-Be time for concretes designed by ACI method

4.4 Hardened Concrete Tests

4.4.1 Compressive Strength Test

As stated before, this study's test includes both the 7 day and 28 day's results for compressive strength. All Figures; 22, 23, 24 and 25 demonstrate that the amount of compressive strength has a sharp rise as the concrete class changes to the higher one in the field of strength. However, in all classes and both manners, the maximum amount is for the samples that are cured in the Water tank and the minimum amount is for the Outside curing regime. The variation amount of each class, in each curing regimes for both BRE and ACI, are as follows: 63.5 MPa, 46.85 MPa and 37.33 MPa then 74.2 MPa, 74.89 MPa and 60.63 MPa for 7 days; 23.42 MPa, 103.12 MPa and 37.33 MPa then 61.63 MPa , 156.71 MPa and 213.98 MPa for 28 days.

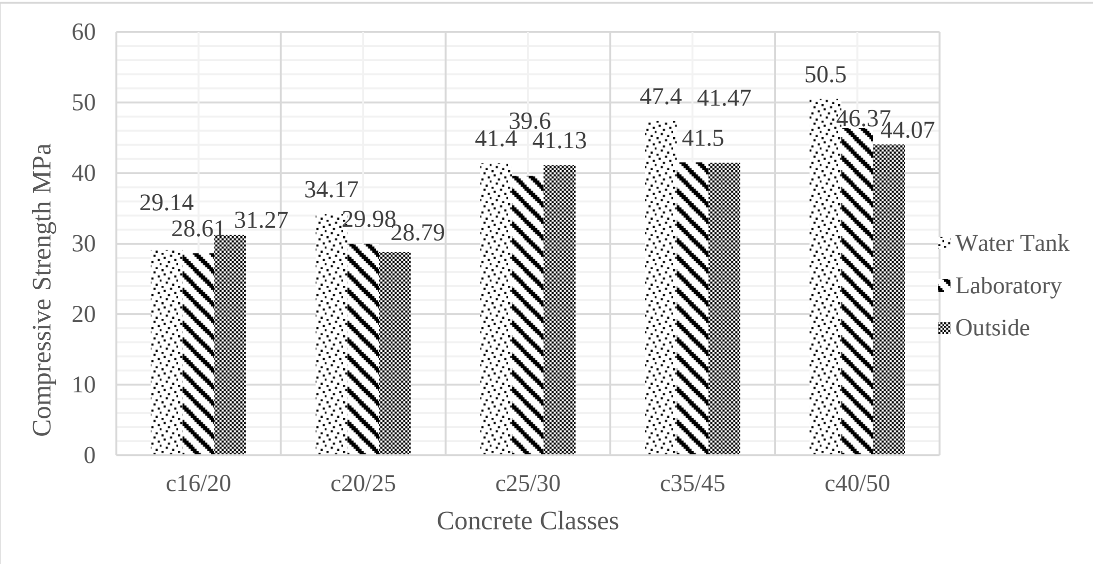


Figure 22: Compressive Strength results at 7days for concretes designed by BRE method

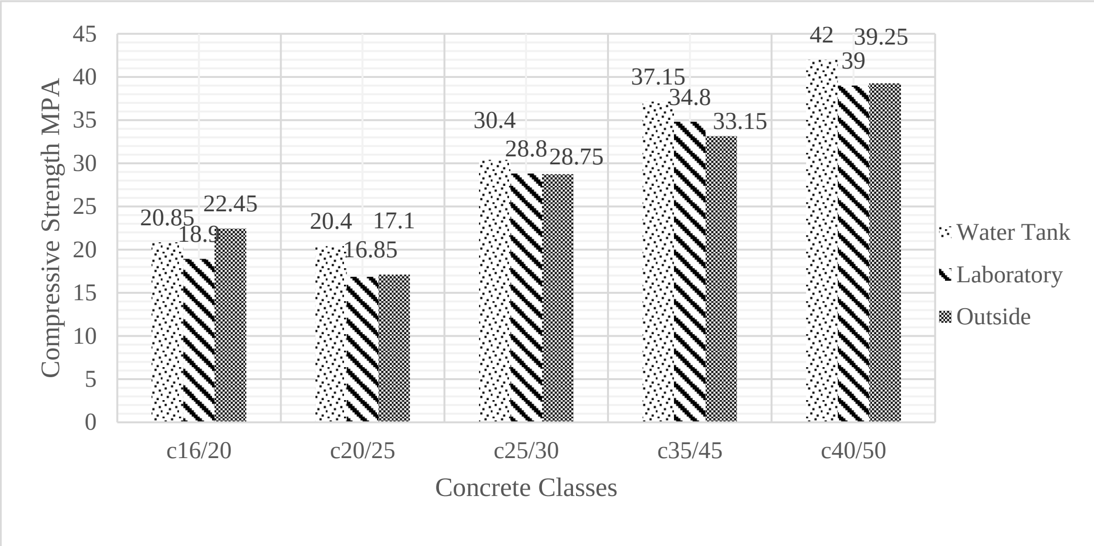


Figure 23: Compressive Strength results at 7days for concretes designed by ACI method

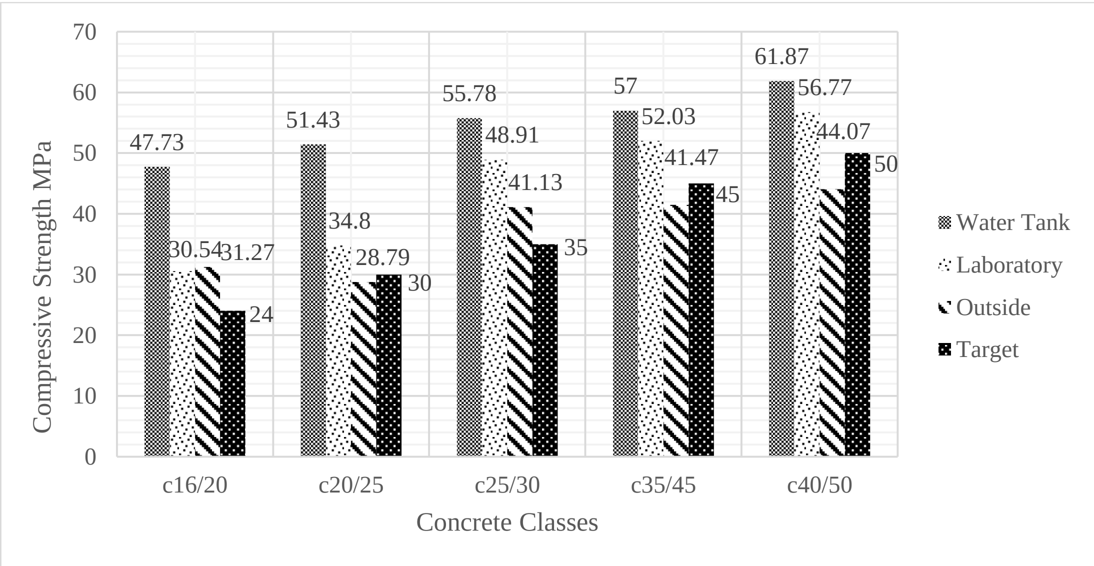


Figure 24: Compressive. Strength results at 28 days for concretes designed by BRE method

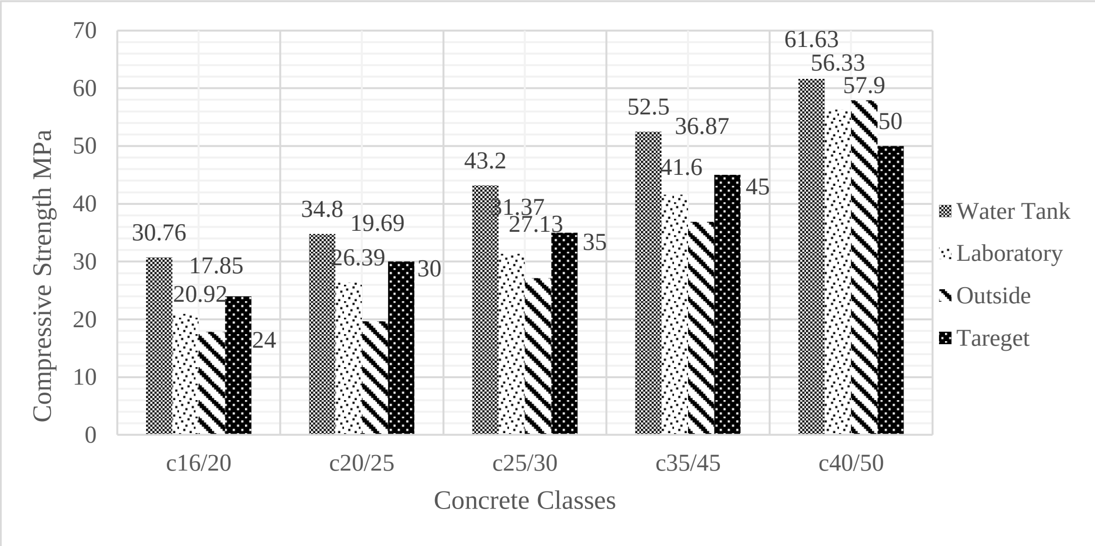


Figure 25: Compressive Strength results at 28 days for concretes designed by ACI method

According to the figures above, after 7 days the average for the compressive strength for water tank, laboratory and outside curing regimes in BRE and ACI which increases sharply are: 40.52 MPa, 37.21 MPa, 37.34 MPa and 30.16 MPa, 27.67 MPa, 28.14 MPa. in average the BRE results are 14.46% more than ACI ones. after 28 days curing again with a sharp rising the average for each curing condition in BRE and ACI as mentioned above are: 54.76 MPa, 44.61 MPa, 34.35 MPa and 44.5 MPa, 35.32 MPa, 31.88 MPa with the 9.95% higher in amount for the BRE mix design in comparison with ACI. For example, in 7 days curing and 28 days curing in BRE mix design the amount for the water tank has the highest amount among the others like it is 4.25% more than laboratory and 4.08% more than outside in 7days and 10.21% more than laboratory and 18.9% more than outside curing regime in 28 days.

In this part, as the strength rises, the average rebound for Schmidt hammer test rises too in all three curing regimes. Reason being that they have direct relationship to one another.

The minimum amount, as always, belongs to C16/20 and the maximum amount is for C40/50 as shown in figures 26 to 31, water tank, laboratory and outside, in BRE and ACI. In all classes the changes between the maximum and minimum amount at 7 days in BRE is 26.82% and in ACI 33.65%. It can be also concluded that at 28 days the results for BRE is 12.9% and ACI is 33.41%.

It can be seen the significant differences between the highest and lowest amount, an example of this is that at 28 days in BRE, Class C20/25, is 28.22%. This kind of change also happens in other classes, mix design and at 7days. As it is illustrated in the figures, as the strength of the concrete classes increase, the compressive strength and Schmidt Hammer increases also. More simply put, the more strength, the more capability for compressive strength and more stiffness for the sample.

It could be seen that the compressive strength for the samples in water tank has significantly higher results in each class, mix designs and duration. In each class the sample that obtained the lowest results belongs to the samples that were cures outside. For example, in C16/20 for BRE samples for outside curing regime have 20.83% less compressive strength than for the water tank curing regime and in ACI this amount is 26.55%. On the other hand, this conclusion can be achieved as the amount of water lost is less than the results from other samples that were cured in water tank, therefore causing a lower result in compressive strength. Moreover, in comparison with BRE and ACI, the highest and lowest results are for the BRE mix deign. These differences were also portrayed in compressive strength, revealed in the Schmidt hammer test shown in the figures below.

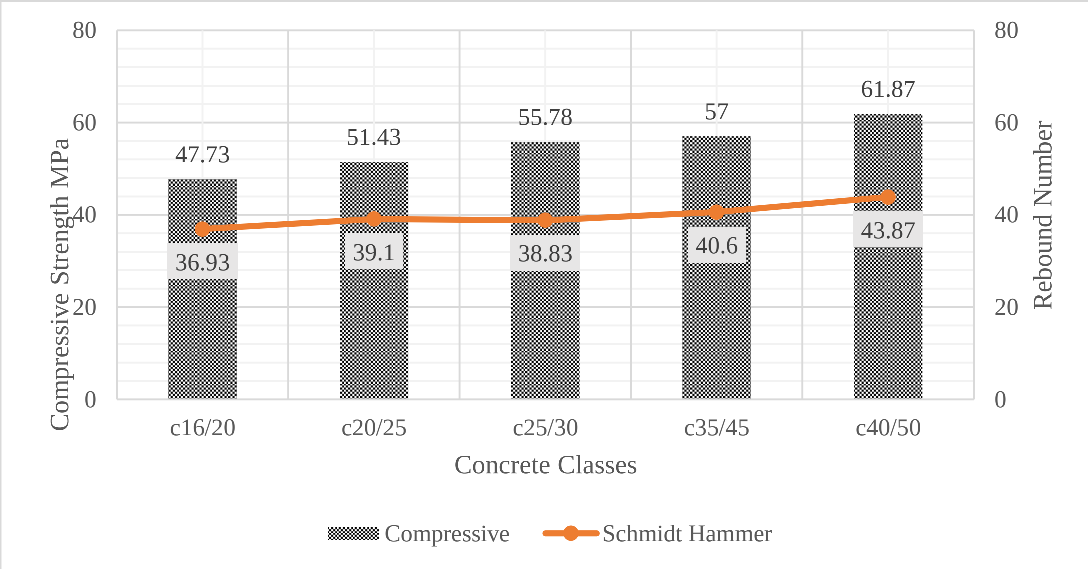


Figure 26: Schmidt hammer versus compressive strength results at 28 days age for concretes designed by BRE method for water tank curing regime

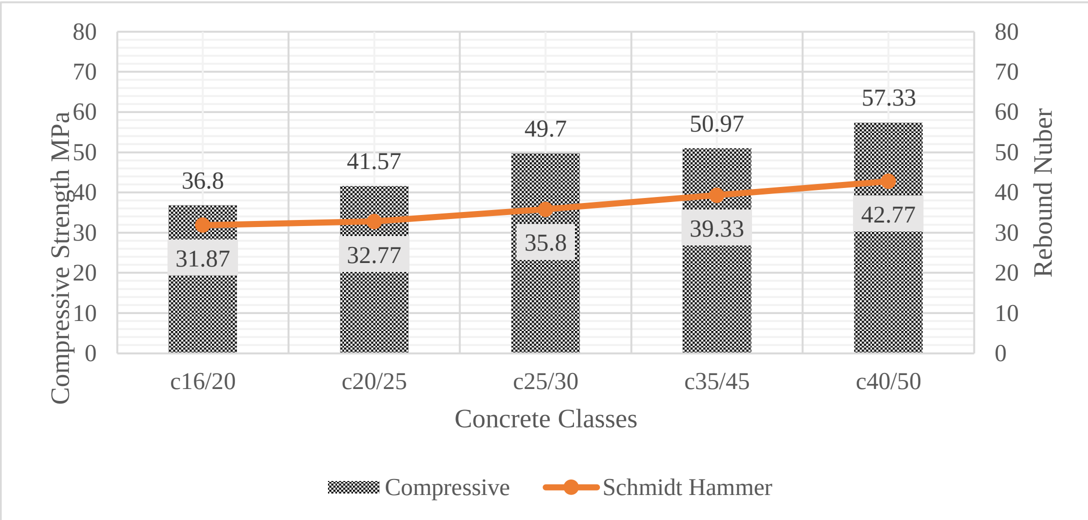


Figure 27: Schmidt hammer versus compressive strength results at 28 days age for concretes designed by BRE method for laboratory curing regime

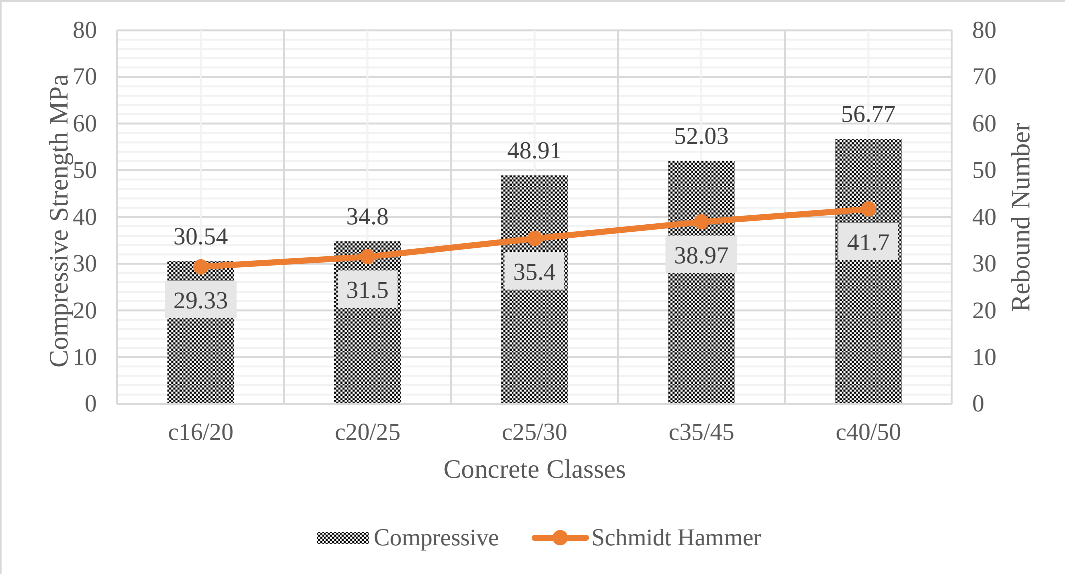


Figure 28: Schmidt hammer versus compressive strength results at 28 days age for concretes designed by BRE method for outside curing regime

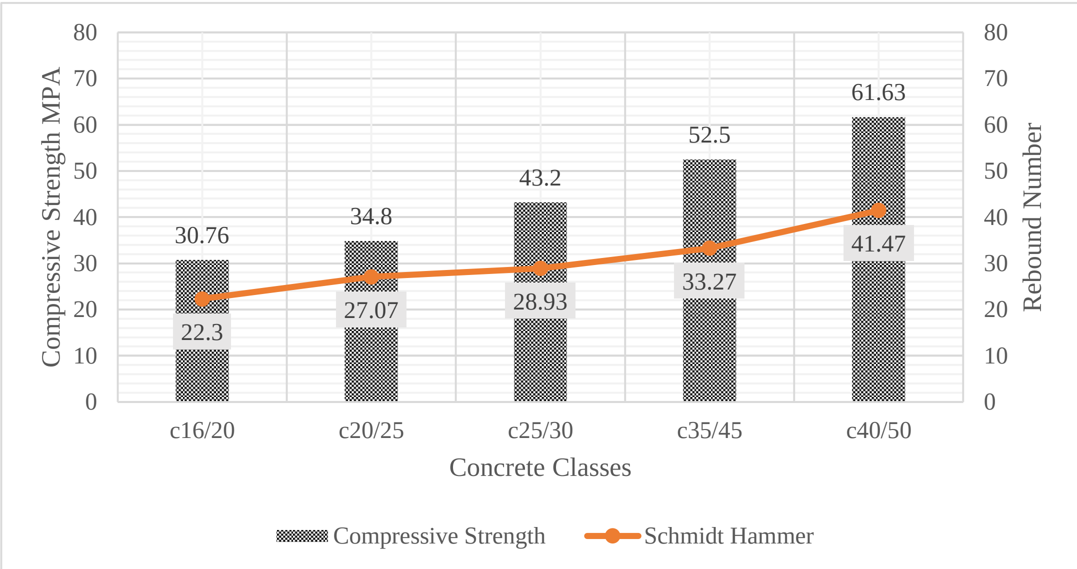


Figure 29: Schmidt hammer versus compressive strength results at 28 days age for concretes designed by ACI method for water tank curing regime

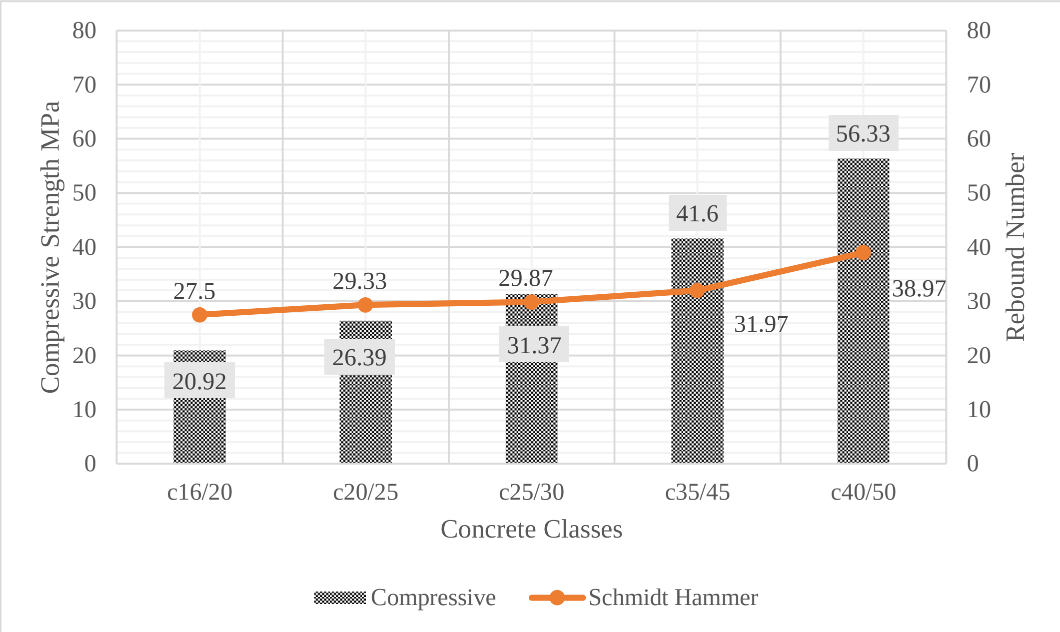


Figure 30: Schmidt hammer versus compressive strength results at 28 days concretes designed by ACI method for laboratory curing regime

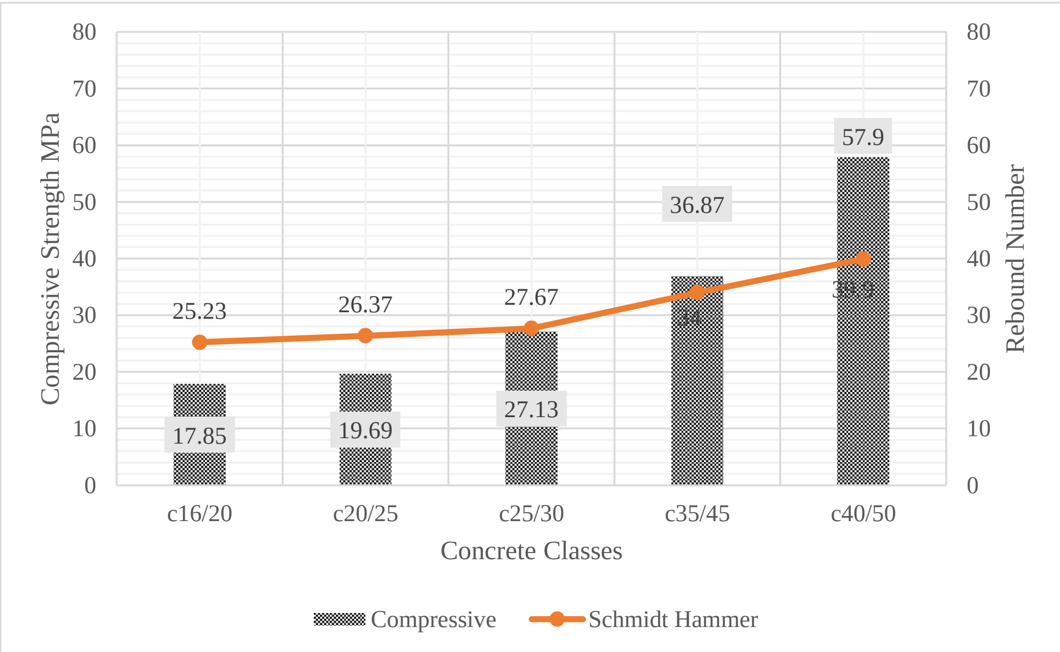


Figure 31: Schmidt hammer versus compressive strength results at 28 days concretes designed by ACI method for outside curing regime

As it is clear from the figures above, Schmidt hammer result and the compressive strength result has a direct relation since the as the compressive amounts increasing, their related Schmidt hammer rebound amount rises too.

Figures 32 to 37 is illustrated the linear relationship between Schmidt hammer Vs. Compressive Strength in 28 days for both BRE and ACI. Furthermore, in tables 8 to 13 other equations with their specific R^2 is given respectively for BRE and ACI.

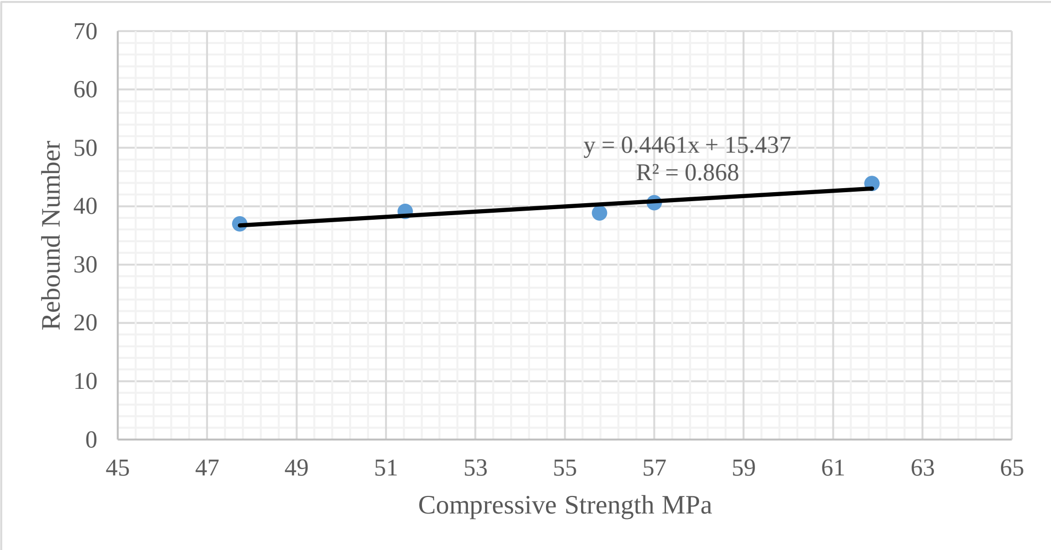


Figure 32: Linear Relationship between Compressive Strength versus Schmidt Hammer in BRE mix design for water tank curing regime

Table 8: Compressive Strength versus Schmidt Hammer in BRE mix design for water tank curing regime relationships

Regression	Equation	R^2
Exponential	$21.703e^{0.0111x}$	0.875
Linear	$0.4461x + 15.437$	0.868
Logarithmic	$24.011\ln(x) - 56.154$	0.854
Polynomial	$0.0238x^2 - 2.1572x + 86.085$	0.918
Power	$3.6598x^{0.5968}$	0.859

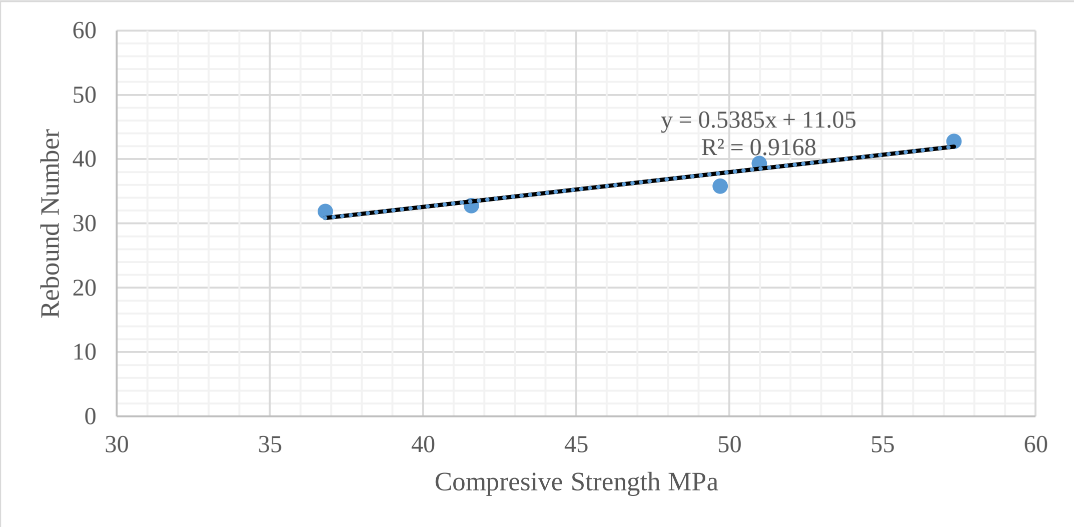


Figure 33: Linear Relationship between Compressive Strength versus Schmidt Hammer in BRE mix design for Laboratory curing regime

Table 9: Compressive Strength versus Schmidt Hammer in BRE mix design for Laboratory curing regime relationships

Regression	Equation	R^2
Exponential	$18.129e^{0.0147x}$	0.929
Linear	$0.5385x + 11.05$	0.916
Logarithmic	$24.433\ln(x) - 57.406$	0.889
Polynomial	$0.0183x^2 - 1.1747x + 50.166$	0.955
Power	$2.7886x^{0.6675}$	0.906

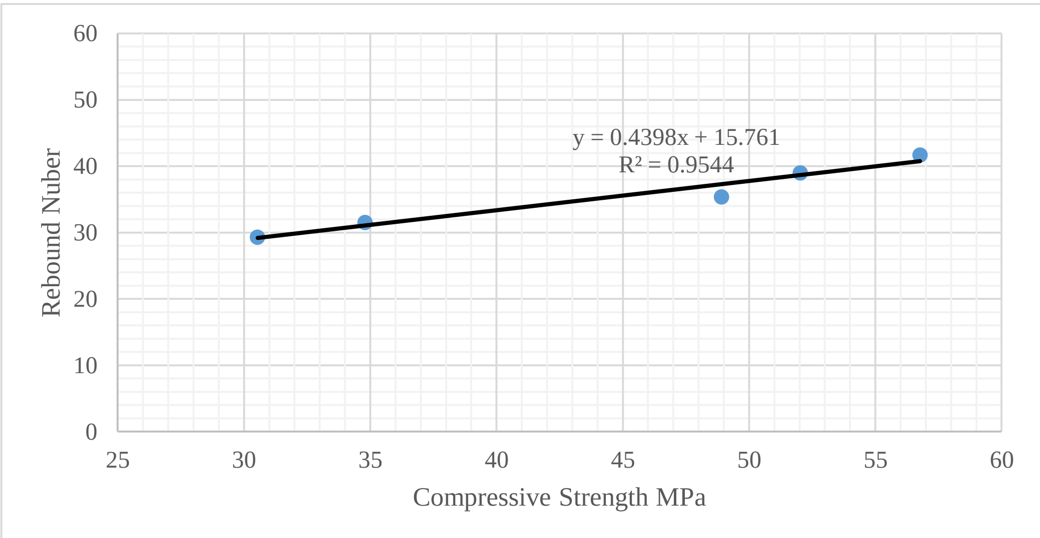
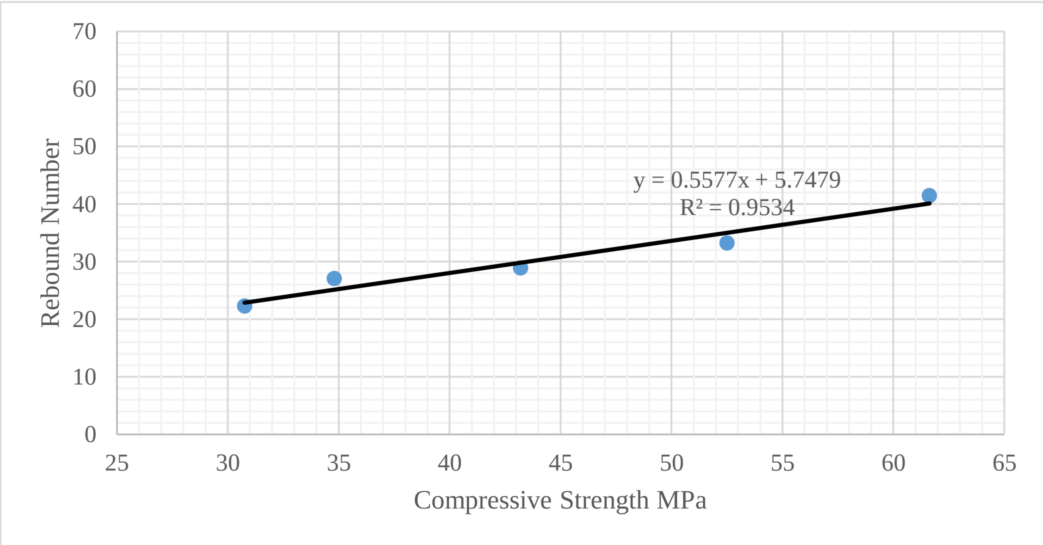


Figure 34: Linear Relationship between Compressive Strength versus Schmidt Hammer in BRE mix design for outside curing regime

Table 10: Compressive Strength versus Schmidt Hammer in BRE mix design for outside curing regime relationships

Regression	Equation	R^2
Exponential	$19.999e^{0.0126x}$	0.966
Linear	0.4398x + 15.761	0.954
Logarithmic	18.293ln(x) - 33.584	0.933
Polynomial	$0.0119x^2 - 0.5894x + 36.746$	0.976
Power	$4.8356x^{0.5257}$	0.951

Figure 35: Linear Relationship between Compressive Strength versus Schmidt



Hammer in ACI mix design for water tank curing regime

Table 11: Compressive Strength versus Schmidt Hammer in ACI mix design for water tank curing regime relationships

Regression	Equation	R^2
Exponential	$13.482e^{0.0179x}$	0.955
Linear	0.5577x + 5.7479	0.953
Logarithmic	24.406ln(x) - 61.275	0.928
Polynomial	$0.0076x^2 - 0.1395x + 20.81$	0.966
Power	$1.5241x^{0.7911}$	0.948

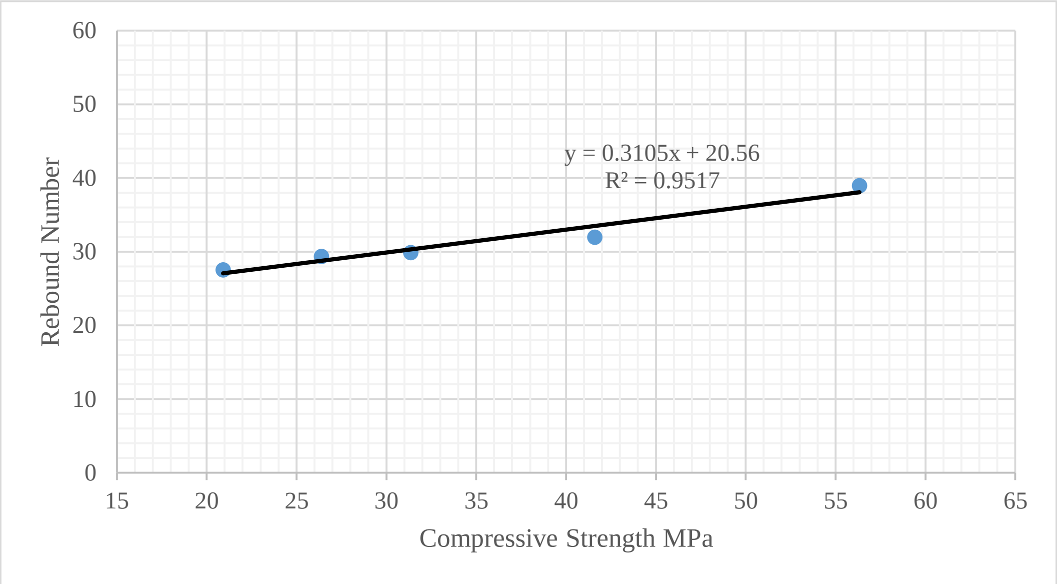


Figure 36: Linear Relationship between Compressive Strength versus Schmidt Hammer in ACI mix design for Laboratory curing regime

Table 12: Compressive Strength versus Schmidt Hammer in ACI mix design for Laboratory curing regime relationships

Regression	Equation	R^2
Exponential	$22.452e^{0.0094x}$	0.966
Linear	$0.3105x + 20.56$	0.951
Logarithmic	$10.829\ln(x) - 6.4153$	0.885
Polynomial	$0.0059x^2 - 0.1498x + 28.531$	0.987
Power	$9.8392x^{0.3302}$	0.912

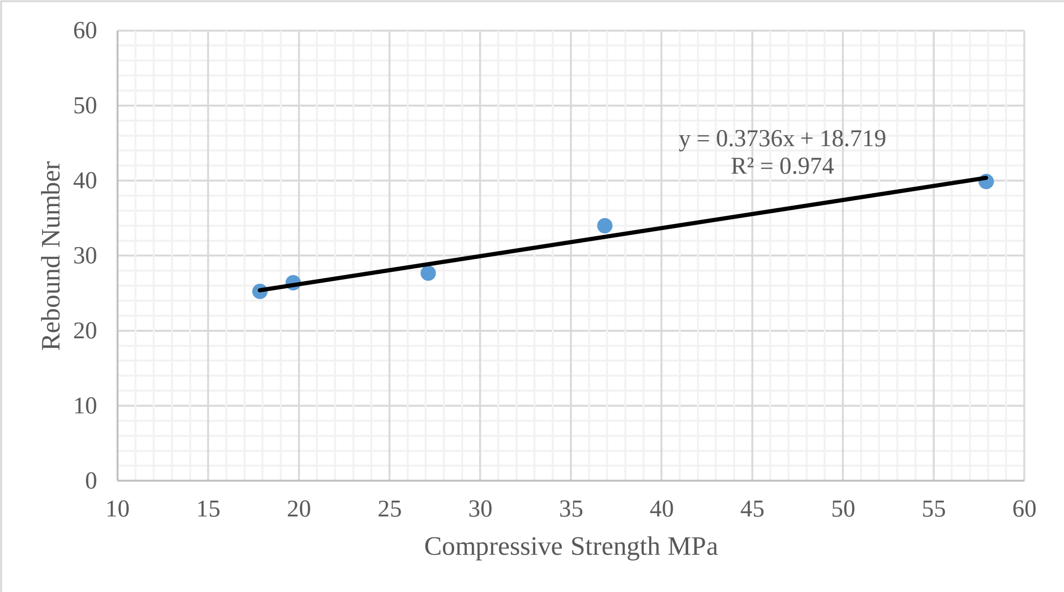


Figure 37: Linear Relationship between Compressive Strength versus Schmidt Hammer in ACI mix design for outside curing regime

Table 13: Compressive Strength versus Schmidt Hammer in ACI mix design for outside curing regime relationships

Regression	Equation	R^2
Exponential	$20.826e^{0.0116x}$	0.962
Linear	$0.3736x + 18.719$	0.974
Logarithmic	$12.626\ln(x) - 11.861$	0.962
Polynomial	$-0.0021x^2 + 0.5367x + 16.162$	0.971
Power	$7.9521x^{0.3961}$	0.968

These regression models and rebound numbers representing compressive strength always apply to the one specific concrete they were designed for and do not work with others. The aim of this analysis was to show how such models may be created for any concrete.

4.4.2 Flexural Strength Test

In this test, there is no consistent rising or falling portrayed from the tests results. Additionally, there is not a constant rate for both BRE and ACI methods as it is illustrated in the figure 38 and figure 39.

In all of the experiments and results, there are significant rises and falls. In BRE, there is a rise of 12.51% from C16/20 to C20/25 and fall of 10% in C25/30 then the amount gradually rises in water tank. There is a 7% rise from C16/20 to C20/25 then a 3% fall for the C25/30 for the Laboratory as examples throughout the concrete classes in all regimes. The same is also portrayed in ACI, for example; from C16/20 there is a 6% fall from C16/20 to C20/25 and then continuous increase to the C35/45 with the rate of 20.2% in water tank. The laboratory and outside samples also portrayed the increase and decrease fluctuation in their results. Similar to the precedent test, the samples obtaining highest results were water tank samples both in BRE and ACI. Example of this are; for BRE C16/20, the results for the water tank, in comparison with the two other regimes, are 7% and 14.28% more than laboratory and outside. The rate for ACI is slightly higher, in the same class, 34% and 54% more than laboratory and outside. This shortage is common and happens in all classes, both in mix and designs.

Similar to the other tests carried out, the maximum amount of flexural strength is for the water tank curing regime's samples, at 28 days for both ACI and BRE, that is 6.79 MPa in C20/25 and 6.8 MPa in C35/45 concrete classes. The minimum amount for flexural strength obtained is for the outside curing regime that is 3.85 MPa in C20/25 and 1.5 MPa in C16/20 for both BRE and ACI.

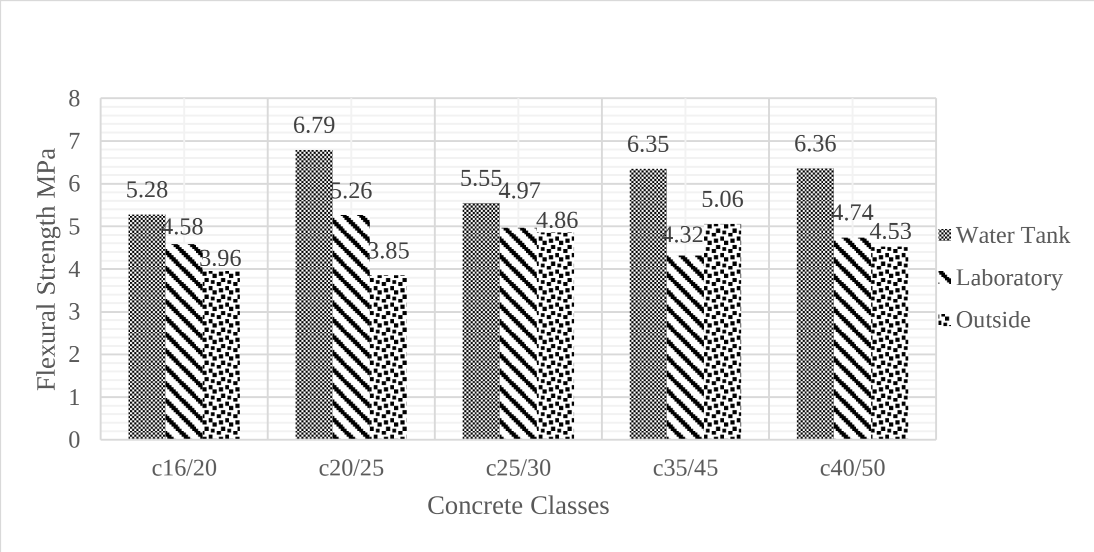


Figure 38: Flexural strength at 28 days for concretes designed by BRE method

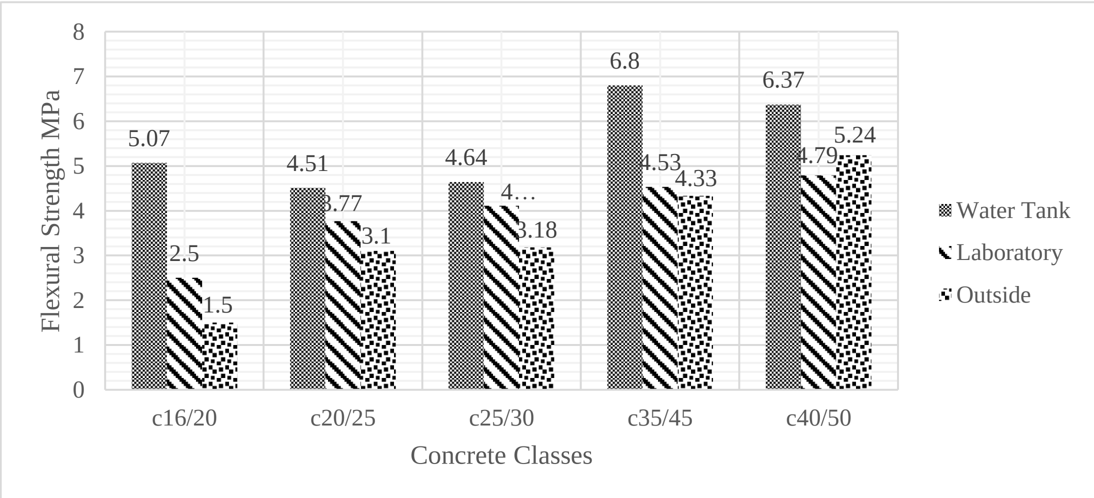


Figure 39: Flexural strength at 28 days for concretes designed by ACI method

In addition, from the figure 38 and figure 39 it is shown that the average amount of flexural strength for the result in BRE and ACI mix designs for water tank, laboratory and outside are: 6.06 MPa, 4.77 MPa, 4.45MPa and 5.5MPa, 3.94MPa, 3.47MPa. this shows that in average, the flexural strength result in BRE mix design is 8.9% higher than ACI mix design. moreover, for instincts, in ACI the average strength for water tank is 16.52% more than laboratory and 22.63% more than outside curing condition.

In this section of my study, the relationship between flexural and compressive strength will be discussed using and referring to the figures provided. Table 14 below shows the ratio of the compressive and flexural strength in BRE and ACI mix designs.

Table 14: Compressive to Flexural strength ratio for BRE and ACI mix designs

BRE									
concrete class	water tank			Laboratory			Outside		
	Flexural	Compressive	ratio %	Flexural	Compressive	ratio %	Flexural	Compressive	ratio %
C16/20	5.28	47.73	11.06	4.58	36.8	12.45	3.96	30.54	12.97
C20/25	6.79	51.43	13.20	5.26	41.57	12.65	3.85	34.8	11.06
C25/30	5.55	55.78	9.95	4.97	49.7	10	4.86	48.91	9.94
C35/45	6.35	57	11.14	4.32	50.97	8.48	5.06	52.03	9.73
C40/50	6.36	61.87	10.28	4.74	57.33	8.27	4.53	56.77	7.98
ACI									
concrete class	water tank			Laboratory			Outside		
	Flexural	Compressive	ratio %	Flexural	Compressive	ratio %	Flexural	Compressive	ratio %
C16/20	5.07	30.76	16.48	2.5	20.92	11.95	1.5	17.85	8.40
C20/25	4.51	34.8	12.96	3.77	26.39	14.29	3.1	19.69	15.74
C25/30	4.64	43.2	10.74	4.11	31.37	13	3.18	27.13	11.72
C35/45	6.8	52.5	12.95	4.53	41.6	10.89	4.33	36.87	11.74
C40/50	6.37	61.63	10.34	4.79	56.33	8.50	5.24	57.9	9.05

In BRE mix design, for water tank and laboratory condition there is a rise from C16/2to C20/25 then the amount has the non-constant changes. in outside, however, it starts with decreasing from C16/20 to C20/25. In ACI mix design, there is no rhythm in changes. in all curing regimes there is a fluctuation in changes.

In addition, Figures 40, 41 and 42 that are all at 28 days for BRE. There is a rise at first and then it gradually descends. It could be observed that the results ascend for the water tank and laboratory curing regimes. However, although the outside condition results rise up until C20/25 it significantly descends after that. The amount for variation is as follows; 0.3151, 0.1 and 0.2293. For the ACI method of mix design, shown in Figures 43, 44 and 45, the water tank's sample results decline at first and then incline again. Both of the other two sample results only gradually rising though, there is no descent in their results. The variation amounts are as follows: 0.86 MPa, 0.64

MPa and 1.59 MPa. Although the structure of each test is different, the results are the same and it can be concluded from the results the superiority of the water tank in comparison to the two other conditions.

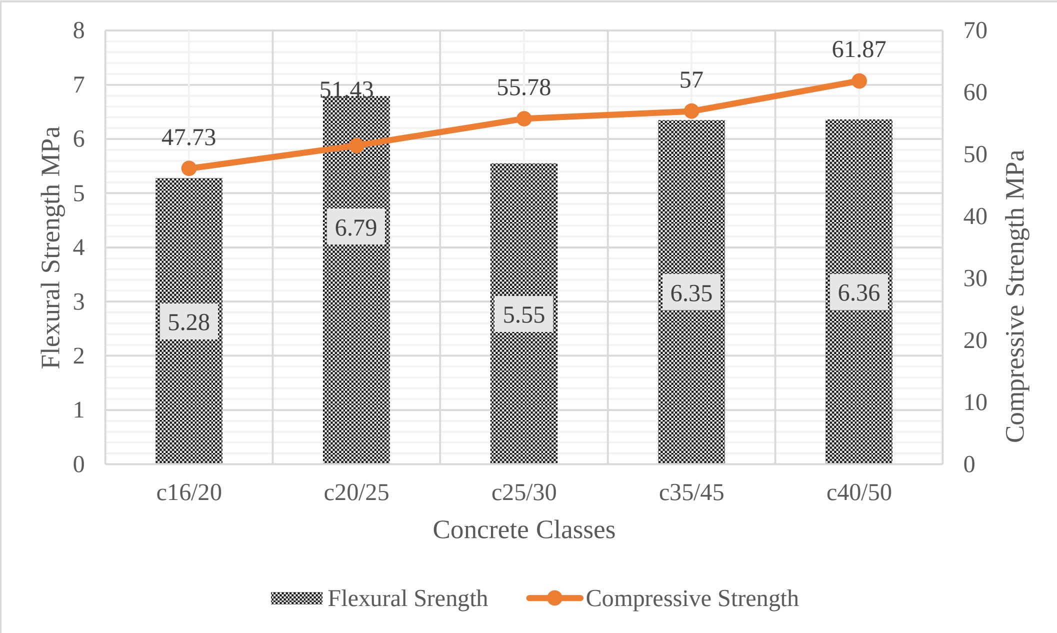


Figure 40: Flexural strength versus compressive strength results at 28 days for concretes designed by BRE method for water tank curing regime

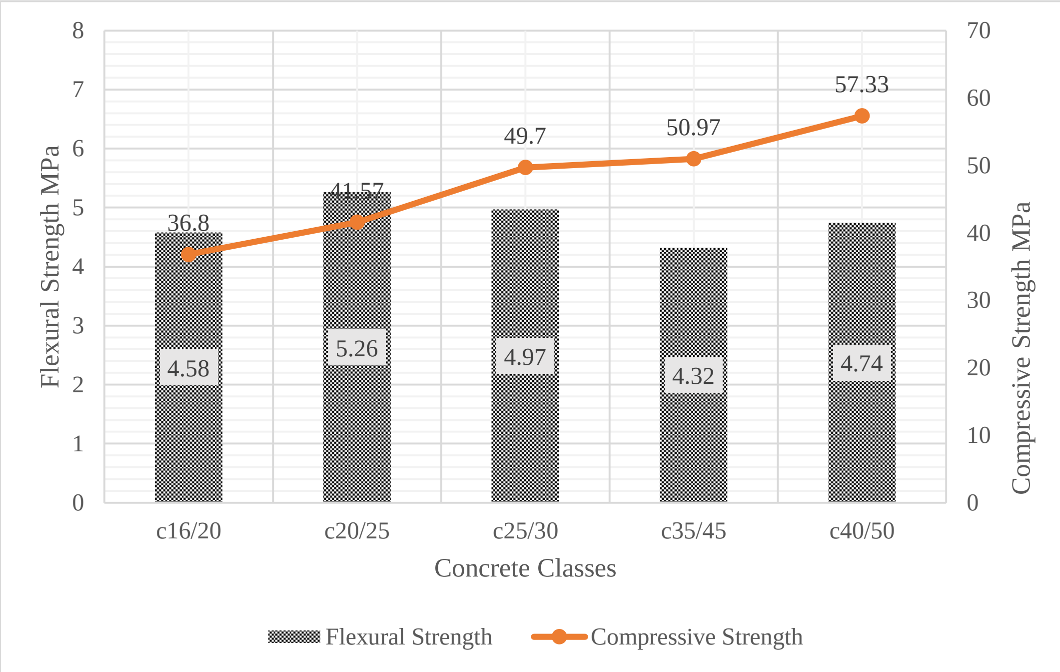


Figure 41: Flexural strength versus compressive strength results at 28 days for concretes designed by BRE method for laboratory curing regime

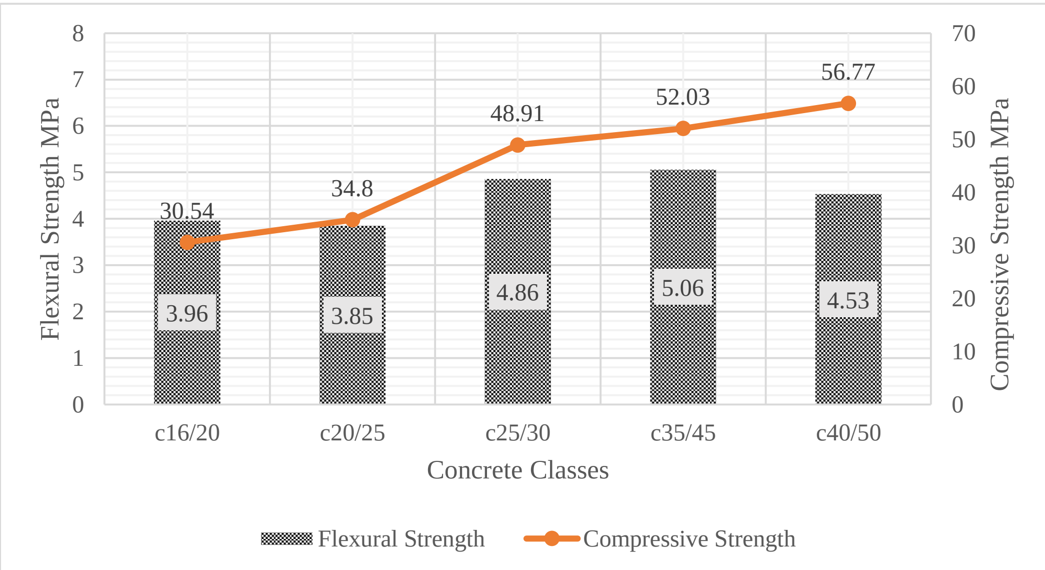


Figure 42: Flexural strength versus compressive strength results at 28 days for concretes designed by BRE method for outside curing regime

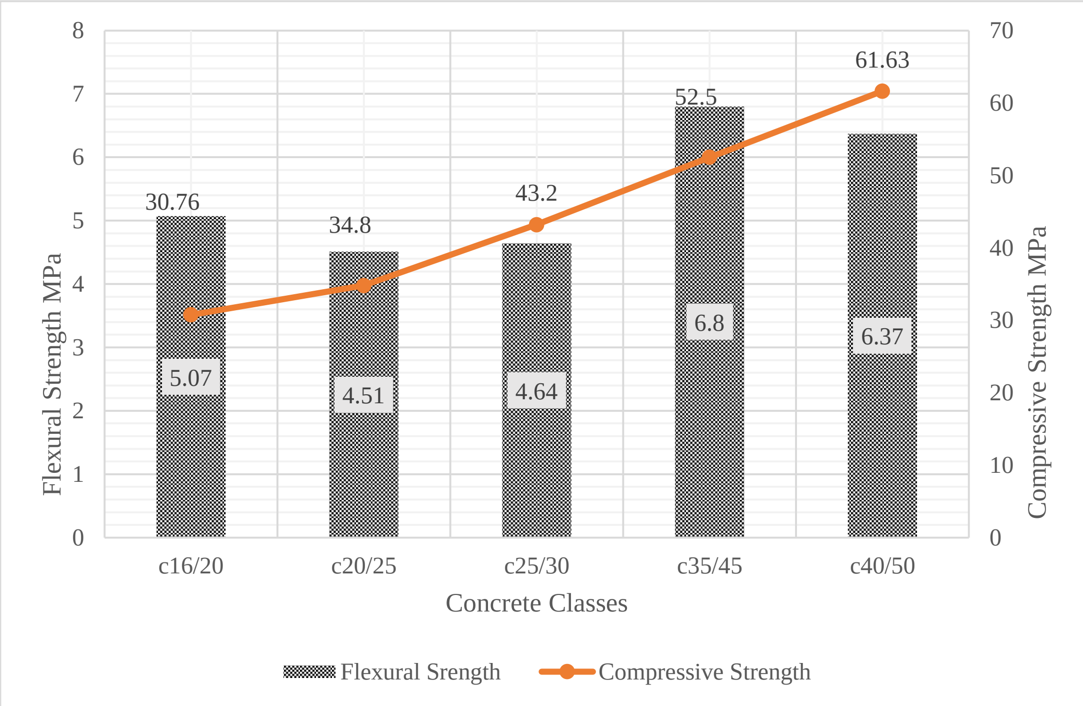


Figure 43: Flexural strength versus compressive strength results at 28 days for concretes designed by ACI method for water tank curing regime

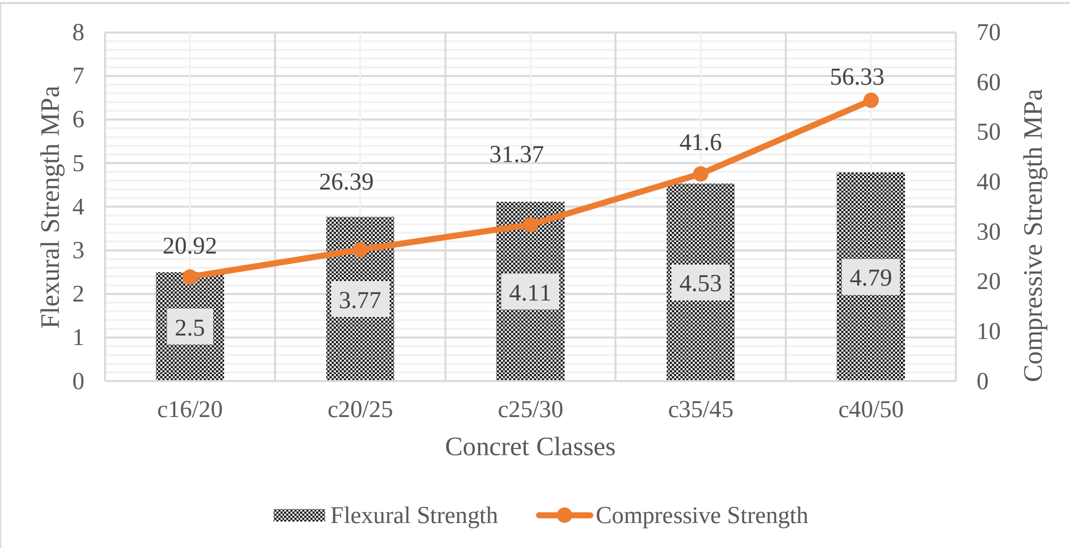


Figure 44: Flexural strength versus compressive strength results at 28 days for concretes designed by ACI method for laboratory curing regime

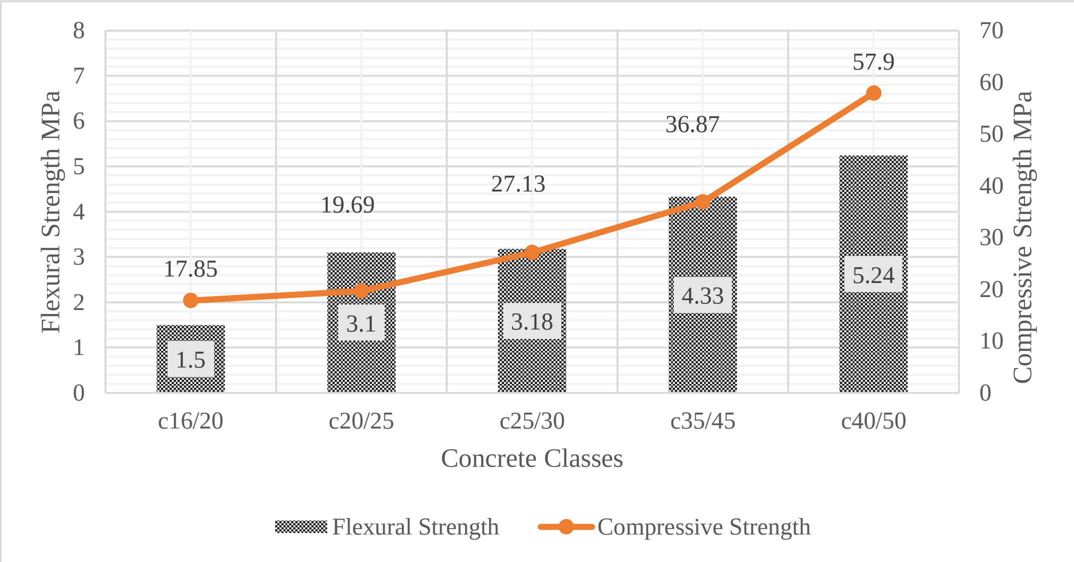


Figure 45: Flexural strength versus compressive strength results at 28days for concretes designed by ACI method for outside curing regime

4.4.3 Splitting Tensile Test

Splitting tensile test is done for BRE and ACI methods, at 28 days, for five different concrete classes. As it is shown in Figures 46 and 47, the tensile strength has gradually risen in both BRE and ACI. It is shown that ACI mix design in this study is 3.1% higher than BRE in average for the water tank curing regime, but in two other curing condition like laboratory and outside is like the previous tests so for the laboratory in BRE mix design the average amount for this test is 3.3% higher and for the outside curing regime the average amount for this test in BRE mix design is 1.7% more than ACI mix design. In addition, for example in BRE mix design, it is determined that the average splitting tensile strength for the water tank curing is 2.9% higher than laboratory regime and 6.3% higher than outside curing regime. Moreover, as it can be seen from these two figures, the rhythm of changes in strength in this test has smooth increasing in all curing conditions, however, in the BRE mix design for the first two concrete classes there is a decreasing and from the C25/30 it is shown a rising gradually. This matter is a little bit different for the ACI mix design. For the water tank curing condition there is slight increasing for the concrete classes, but for the other regimes from C16/20 to C25/30 there is a decreasing in strength amount but to the rest of the concrete classes there is sharp rising. In this test, the maximum and minimum amount for each test result is for to the water tank and outside curing regimes. Through all concrete classes in BRE, the maximum rate for the splitting tensile strength for C35/45 is 3.68 MPa. The minimum rate for the splitting tensile strength is 1.74 MPa for C20/25 and in ACI the maximum rate is 4.04 MPa for 40/50 and the minimum is 2.1 MPa for C20/25. The variation amount for the BRE method is as follows: 0.13 MPa, 0.216 MPa and 0.59 MPa for water tank cured samples, for the laboratory and outside cured samples the ACI method is: 0.13 MPa, 0.216 MPa and 0.494 MPa for Water tank cured samples. It can be concluded that the water tank cured samples are stronger than other samples in this test. For example, in C20/25 for BRE samples for outside curing regime have 21.26% less splitting tensile strength than for the water tank curing regime and in ACI this amount is 18.6%.

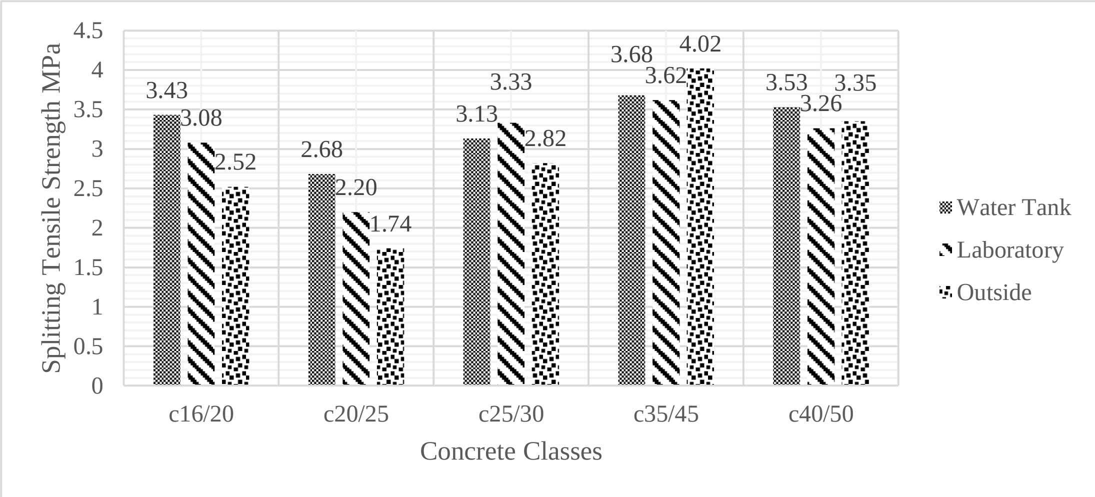


Figure 46: Splitting tensile strength Test at 28 days for concretes designed by BRE

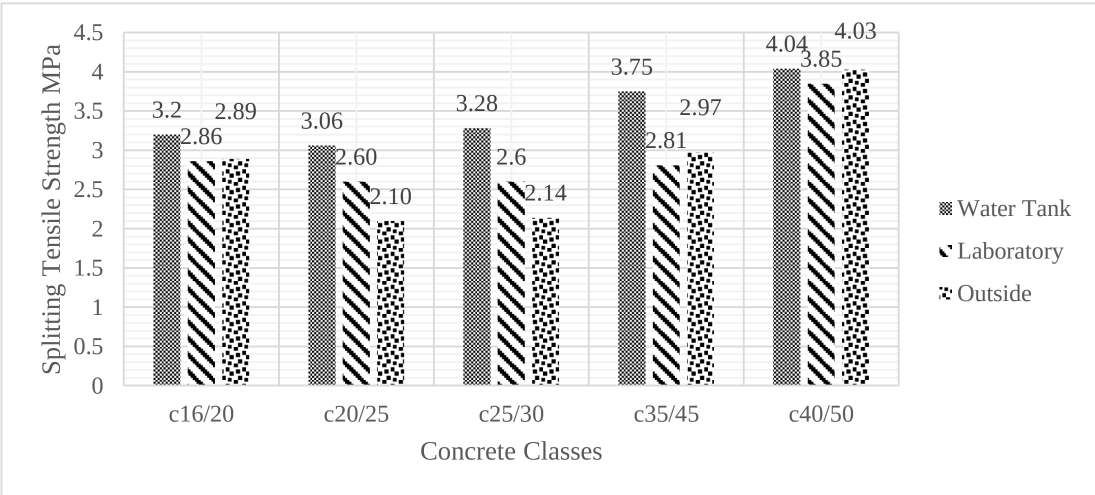


Figure 47: Splitting tensile strength Test at 28 days for concretes designed by ACI

As it is shown below in Figures 48, 49 and 50 for BRE and 51, 52 and 53 for ACI, there is a gradual rise displayed on the graphs. The reason being that as the concrete classes differ with a higher strength, the splitting tensile strength is increased with, somehow gradually, the same rhythm in all curing regimes in both the BRE and ACI methods.

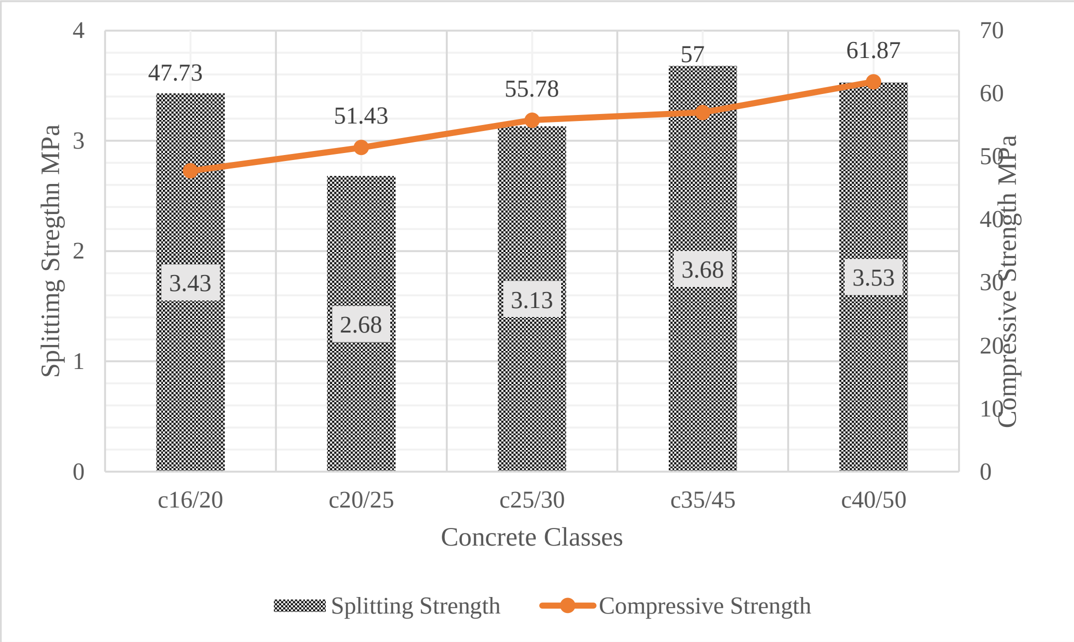


Figure 48: Splitting tensile strength versus compressive strength results at 28 days concretes designed by BRE method for water tank curing regime

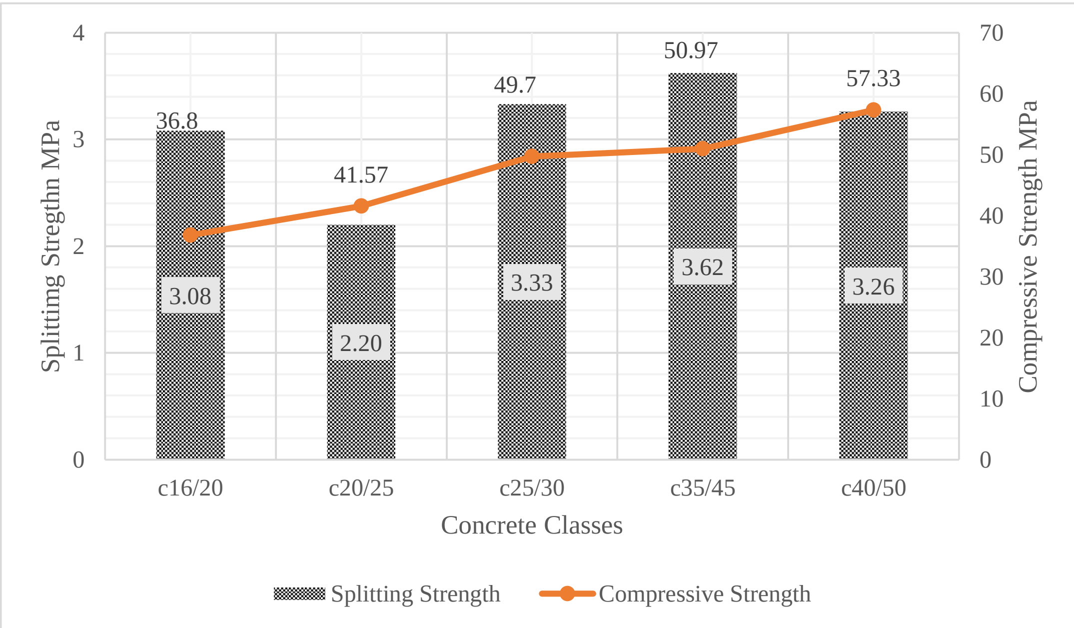


Figure 49: Splitting tensile strength versus compressive strength results at 28 days concretes designed by BRE method for laboratory curing regime

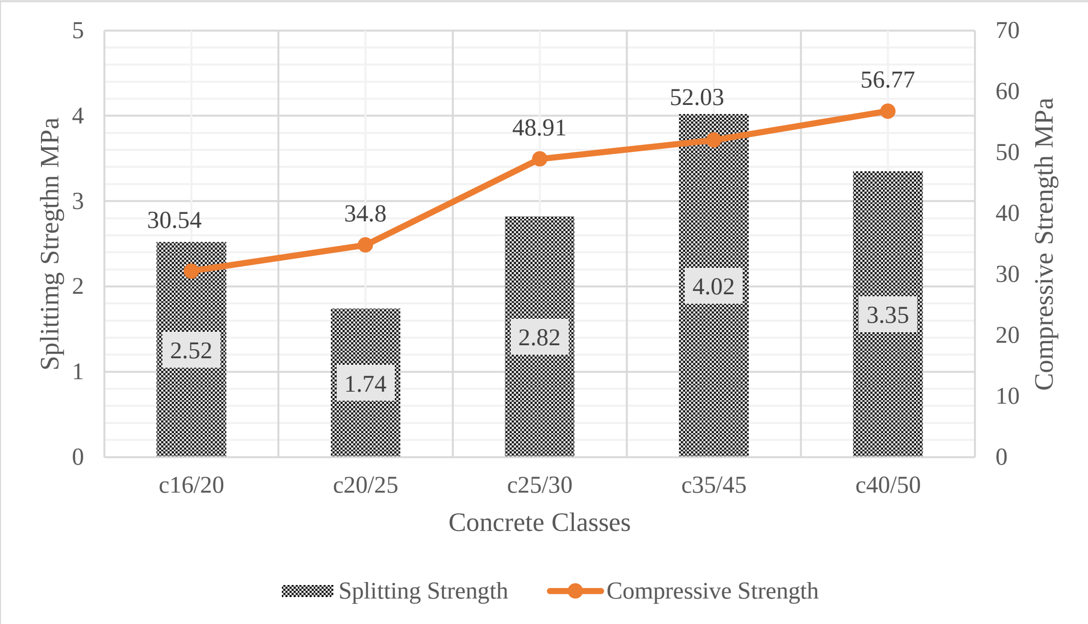


Figure 50: Splitting tensile strength versus compressive strength results at 28 days concretes designed by BRE method for outside curing regime

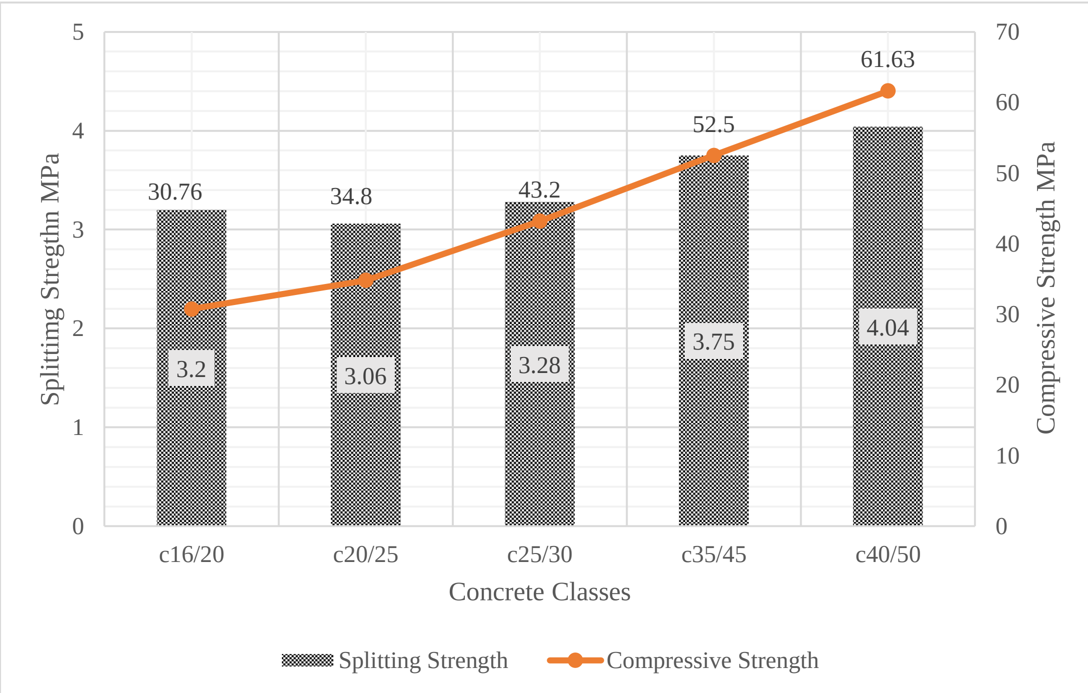


Figure 51: Splitting tensile strength versus compressive strength in 28 period concretes designed by ACI method for water tank curing regime

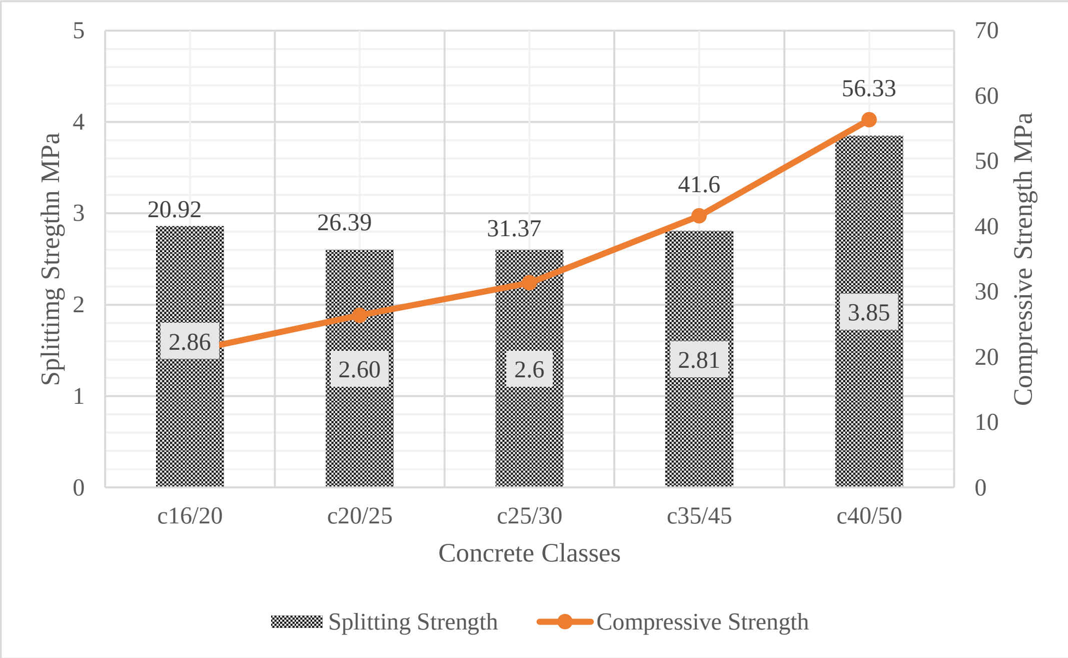


Figure 52: Splitting ensile strength versus compressive strength results at 28 days for concretes designed by ACI method for laboratory curing regime

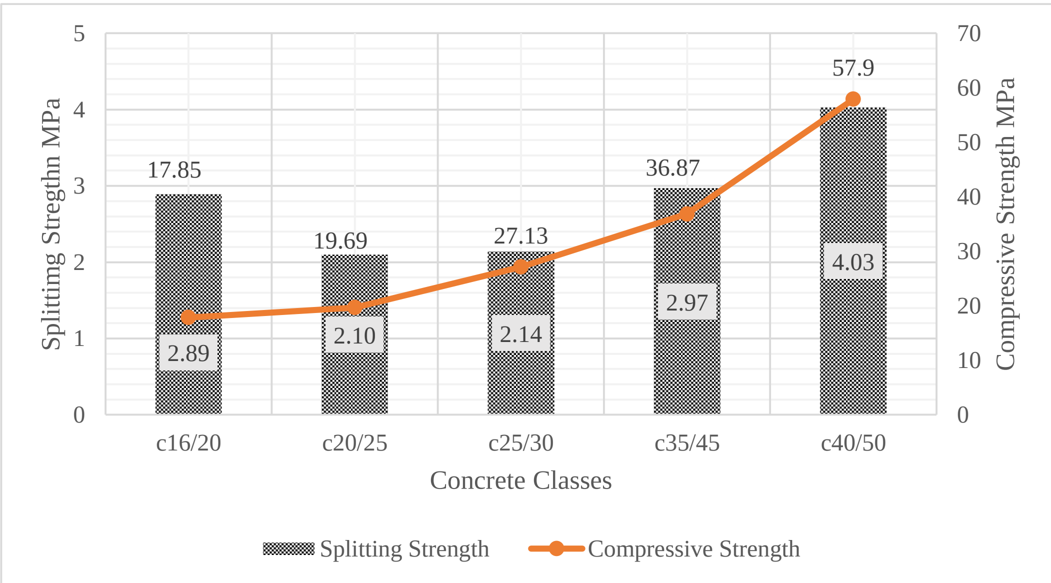


Figure 53: Splitting tensile strength versus compressive strength results at 28 days for concretes designed by ACI method for outside curing regime

In addition to the six previous figures, the splitting tensile strength to compressive strength could be determined which is give in the table 15 below for the BRE and ACI mix designs for all the concrete classes that are used in this study:

Table 15: Compressive to Splitting tensile strength ratio for BRE and ACI mix design

BRE									
concrete class	water tank			Laboratory			Outside		
	Splitting	Compres	ratio %	Splitting	Compres	ratio %	Splitting	Compres	ratio %
C16/20	3.43	47.73	7.19	3.08	36.8	8.37	2.52	30.54	8.25
C20/25	2.68	51.43	5.21	2.20	41.57	5.29	1.74	34.8	5
C25/30	3.13	55.78	5.61	3.33	49.7	7	2.82	48.91	5.77
C35/45	3.68	57	6.46	3.62	50.97	7.10	4.02	52.03	7.73
C40/50	3.53	61.87	5.71	3.26	57.33	5.69	3.35	56.77	5.90
ACI									
concrete class	water tank			Laboratory			Outside		
	Splitting	Compres	ratio %	Splitting	Compres	ratio %	Splitting	Compres	ratio %
C16/20	3.2	30.76	10.40	2.86	20.92	13.67	2.89	17.85	16.19
C20/25	3.06	34.8	8.79	2.60	26.39	9.85	2.10	19.69	10.67
C25/30	3.28	43.2	7.59	2.6	31.37	8	2.14	27.13	7.89
C35/45	3.75	52.5	7.14	2.81	41.6	6.75	2.97	36.87	8.06
C40/50	4.04	61.63	6.56	3.85	56.33	6.83	4.03	57.9	6.96

Another identifiable relationship is splitting tensile and the flexural strength. In this relationship, the changes happen as the strength in each concrete class becomes higher. In both procedures that are used in this study, like other tests called BRE and ACI, the relationship has increased gradually. Evidence of which is shown below in Figures: 54, 55 and 56 for BRE method and 57, 58 and 59 for ACI method.

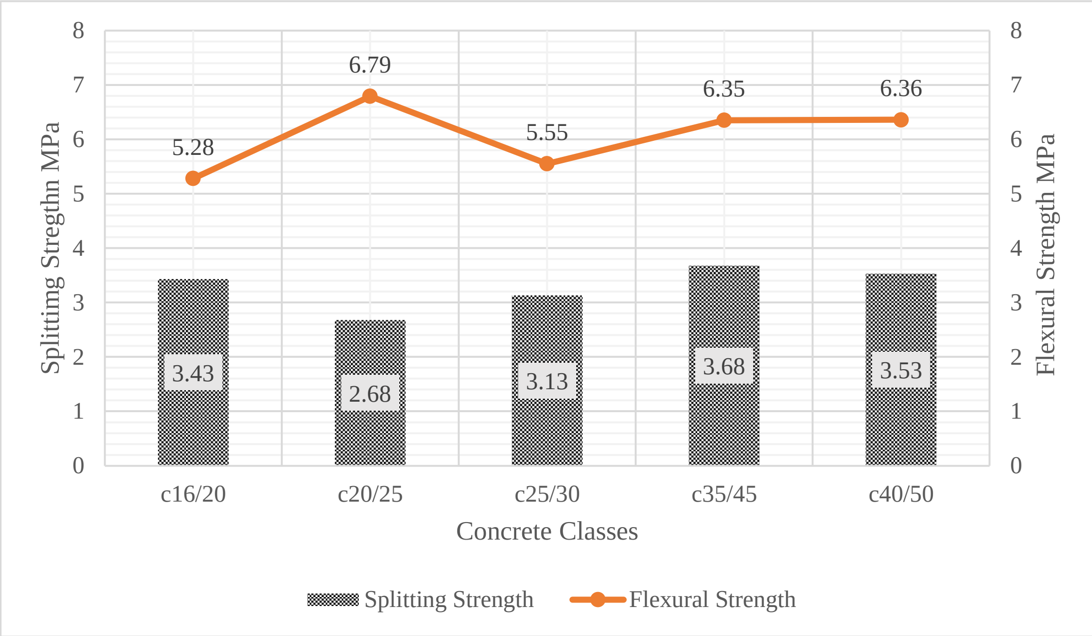


Figure 54: Splitting tensile strength versus flexural strength results at 28 days for concretes designed by BRE method for water tank curing regime

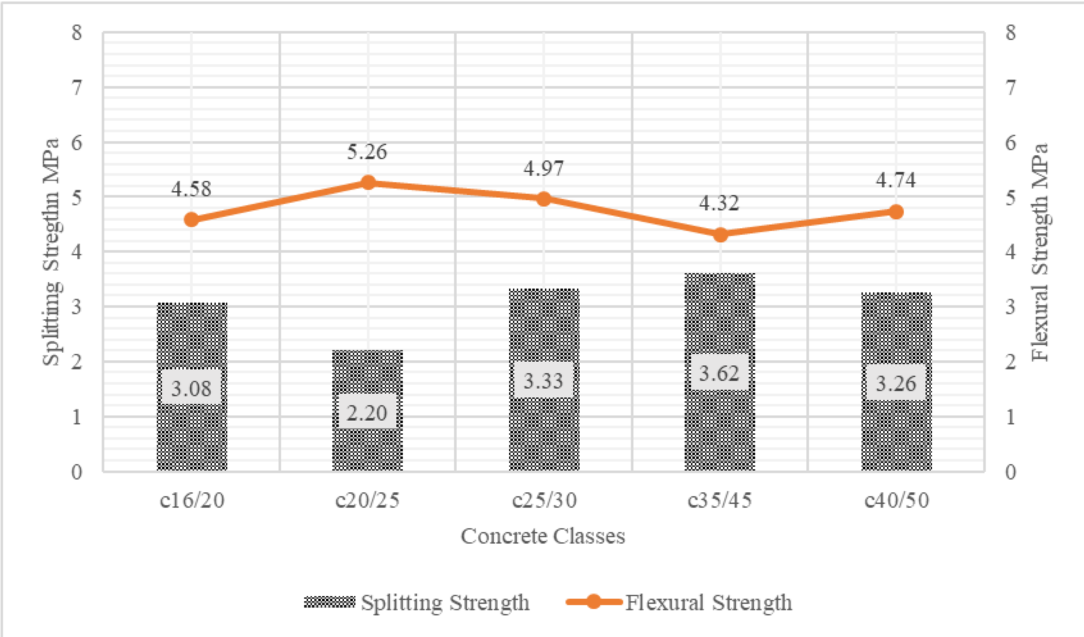


Figure 55: Splitting tensile. strength versus flexural. strength. results at 28 days for concretes designed by BRE method for laboratory curing regime

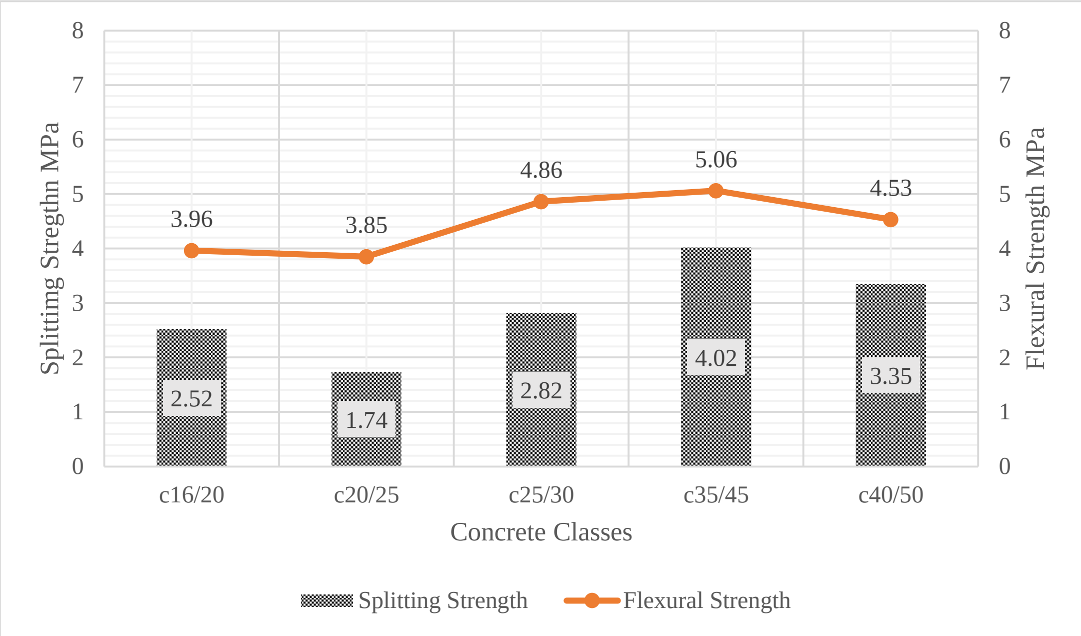


Figure 56: Splitting tensile strength versus flexural strength results at 28 days for concretes designed by BRE method for outside curing regime

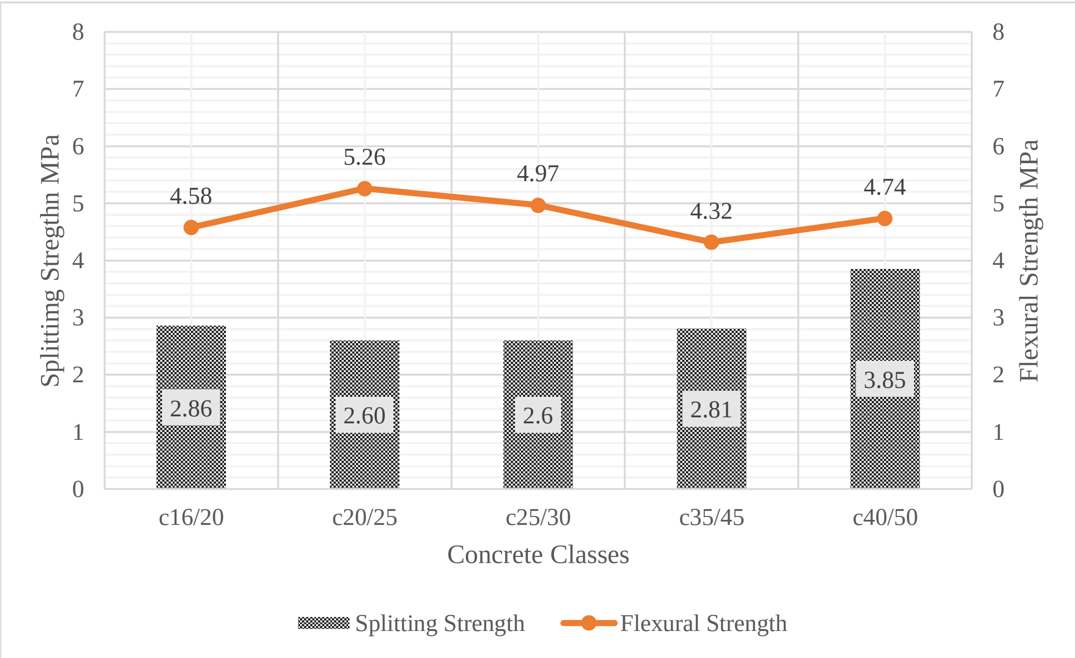


Figure 57: Splitting tensile strength versus flexural strength results at 28 days for concretes designed by ACI method for water tank curing regime

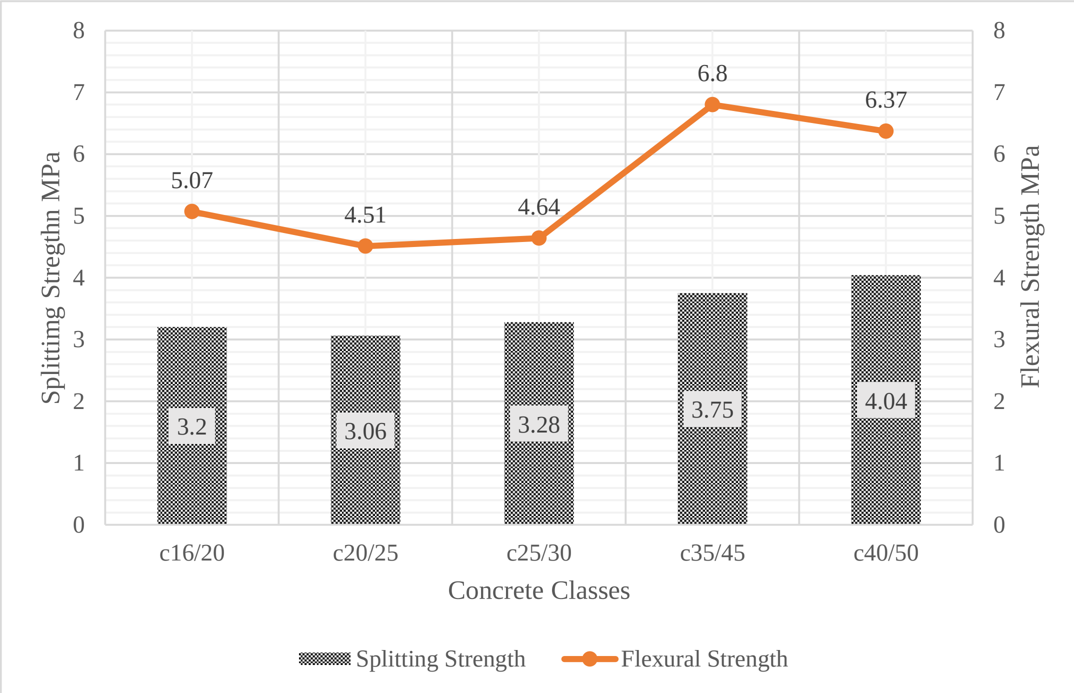


Figure 58: Splitting tensile strength versus flexural strength results at 28 days for concretes designed by ACI method for laboratory curing regime

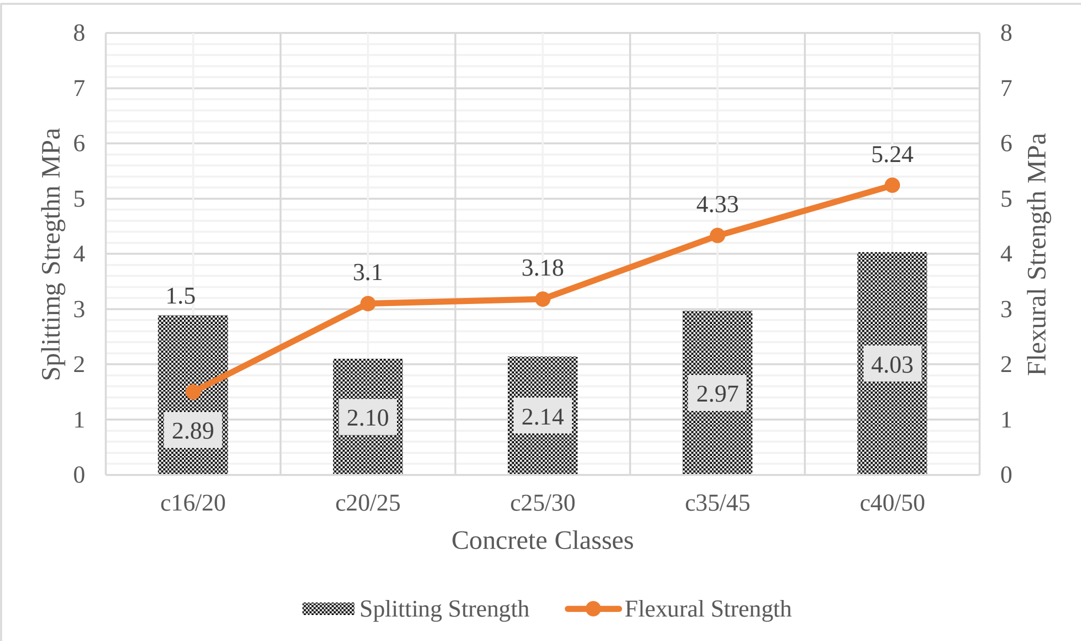


Figure 59: Splitting tensile strength versus flexural strength results at 28 days for concretes designed by ACI method for outside curing regime

In addition to the six previous figures, the splitting tensile strength to flexural strength could be determined which is give in the table 16 below for the BRE and ACI mix designs for all the concrete classes that are used in this study:

Table 16: Splitting tensile to flexural strength ratio for BRE and ACI mix design

BRE									
concrete class	water tank			Laboratory			Outside		
	Splitting	Flexural	ratio %	Splitting	Flexural	ratio %	Splitting	Flexural	ratio %
C16/20	3.43	5.28	64.96	3.08	4.58	67.25	2.52	3.96	63.64
C20/25	2.68	6.79	39.47	2.20	5.26	41.83	1.74	3.85	45
C25/30	3.13	5.55	56.40	3.33	4.97	67	2.82	4.86	58.02
C35/45	3.68	6.35	57.95	3.62	4.32	83.80	4.02	5.06	79.45
C40/50	3.53	6.36	55.50	3.26	4.74	68.78	3.35	4.53	73.95
ACI									
concrete class	water tank			Laboratory			Outside		
	Splitting	Flexural	ratio %	Splitting	Flexural	ratio %	Splitting	Flexural	ratio %
C16/20	3.2	5.07	63.12	2.86	2.5	114.40	2.89	1.5	192.67
C20/25	3.06	4.51	67.85	2.60	3.77	68.97	2.10	3.1	67.74
C25/30	3.28	4.64	70.69	2.6	4.11	63	2.14	3.18	67.30
C35/45	3.75	6.8	55.15	2.81	4.53	62.03	2.97	4.33	68.59
C40/50	4.04	6.37	63.42	3.85	4.79	80.38	4.03	5.24	76.91

4.4.4 Ultrasonic Pulse Velocity (UPV) Test

This test was carried out with all five concrete classes, in three different curing regimes, as mentioned before. These curing regimes are; water tank, laboratory and outside for both BRE and ACI designed mixes. As it is clearly shown, in Figure 60 and Figure 61, almost all the UPV time in each class reaches the maximum amount when the samples were held in the outside condition. Moreover, the average amount of UPV results for BRE mix design in all water tank, laboratory and outside curing regime are higher than for ACI, 2.5% for water tank, 1.45% laboratory and 0.95% for the outside condition. On the other hand, it is shown from the above figures in both

BRE and ACI mix design, the outside curing regime has the highest average amount of UPV results.

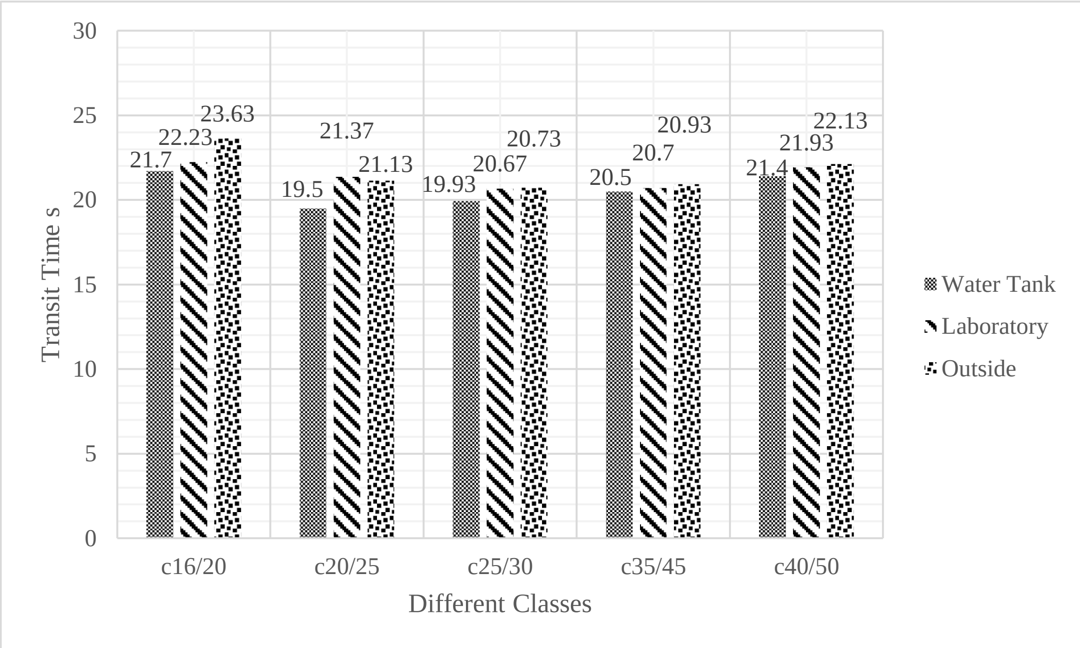


Figure 60: Transit Time for each class at different curing regimes for concretes designed by BRE method

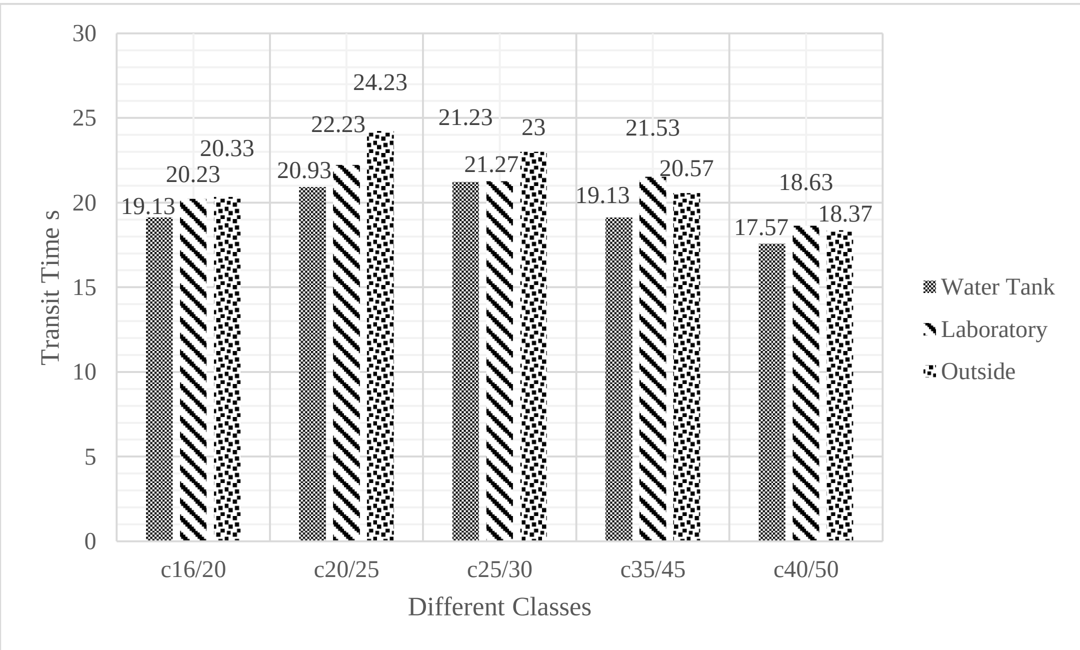


Figure 61: Transit Time for each class at different curing regimes for concretes designed by ACI method

As discussed earlier in this part, since the samples that were put outside for curing regimes have lost their amount of water, they now have more holes and pores. The point being that the samples from the water tank have their amounts of water captured in themselves, in comparison with the outside samples. This could be contributed to a fluctuation in test results. Said results are also effected by the density of samples as the strength of them increases, since the changes in fine, coarse and other materials are included in the samples and results. The variation for each BRE and ACI in each classes are as follow: 1.79, 1.56 and 4.3 BRE and 0.7, 0.39 and 1.15 ACI.

4.4.5 Schmidt Hammer Test

Figures 62 and 63 show the average rebound number that is obtained from the Schmidt hammer test of all concrete classes at different curing regimes both for BRE and ACI methods mix designs. The variation amount for each BRE and ACI methods are as follows respectively: 5.37, 16.63 and 20.89 BRE and 41.88,15.87 and 30.67 ACI.

As it is illustrated from both figures that there is a gradual rise for each class and regime, minimum and maximum amount in BRE and ACI are: 36.93 and 43.87 in the Water tank sample which C16/20 is 8.6% less than C40/50; 31.87 and 42.77 in Laboratory which C16/20 is 14.6% less than C40/50 and 29.33 and 41.7 in the Outside which C16/20 is 17.41% less than C40/50 For BRE; 22.3 and 41.47 Water tank which C16/20 is 30% less than C40/50, 27.5 and 38.97 Laboratory which C16/20 is 17.25% less than C40/50 and 25.23 and 39.9 outside which C16/20 is 22.5% less than C40/50 for ACI.

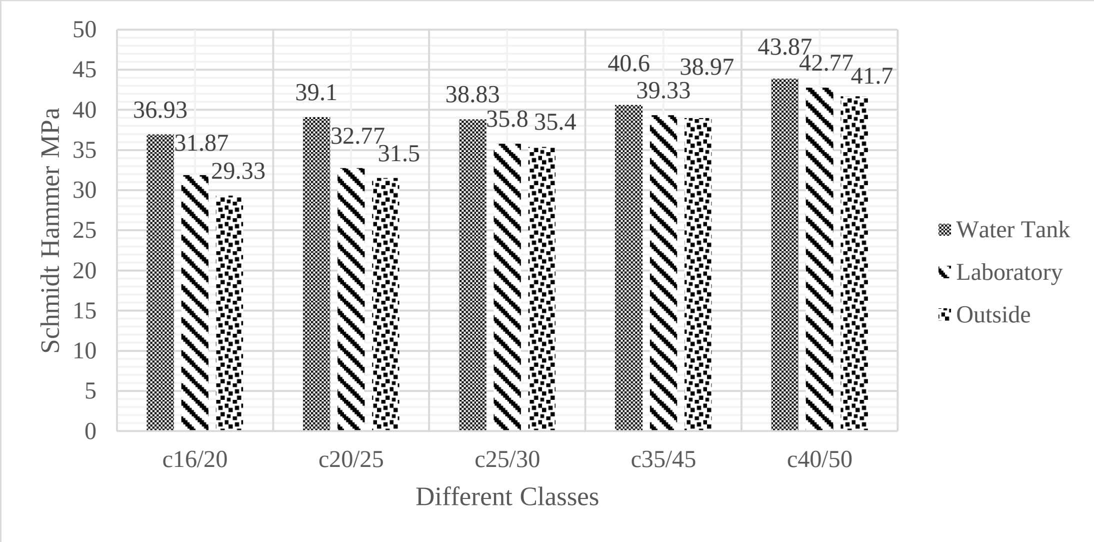


Figure 62: Schmidt Hammer Test results for all concrete classes at different curing regimes for concretes designed by BRE method

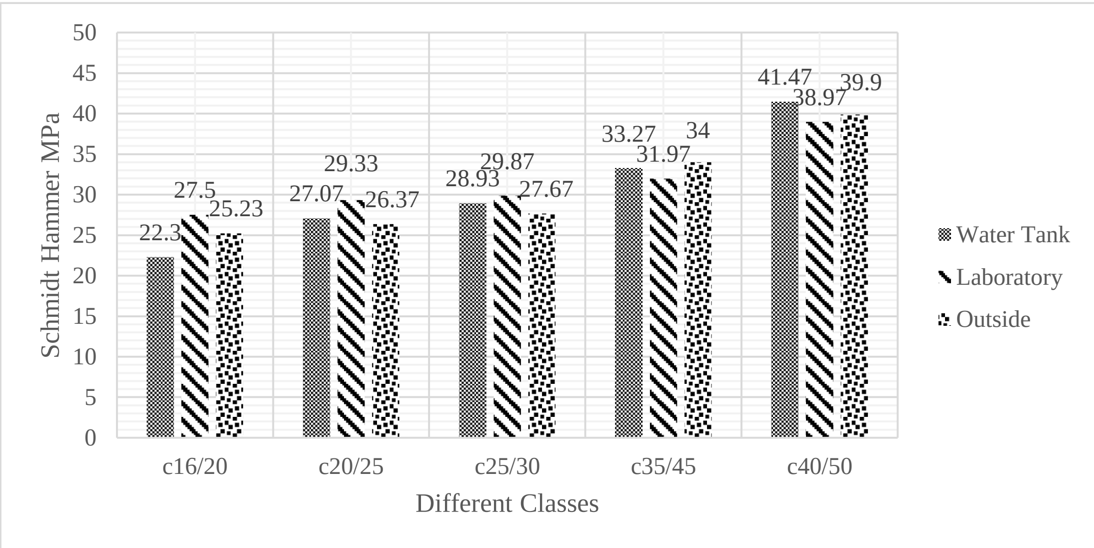


Figure 63: Schmidt Hammer Test results for all concrete classes at different curing regimes for concretes designed by ACI method

4.5 Comparison between BRE and ACI mix designs

4.5.1 Compressive strength

As stated before, All Figures; 22, 23, 24 and 25 demonstrate that the amount of compressive strength has a sharp rise as the concrete class changes. However, in all classes and both mix designs, the maximum amount is for the samples that are cured in the Water tank and the minimum amount is for the Outside curing regime.

According to the figures that mentioned, after 7 days the average for the compressive strength for water tank, laboratory and outside curing regimes in BRE and ACI which increases sharply are: 40.52 MPa, 37.21 MPa, 37.34 MPa and 30.16 MPa, 27.67 MPa, 28.14 MPa. In average the BRE results are 14.46% more than ACI ones. after 28 days curing again with a sharp rising the average for each curing condition in BRE and ACI as mentioned above are: 54.76 MPa, 44.61 MPa, 34.35 MPa and 44.5 MPa, 35.32 MPa, 31.88 MPa with the 9.95% higher in amount for the BRE mix design in comparison with ACI.

In addition, in this part it could be achieved that, as the strength rises, the average rebound for Schmidt hammer test rises too in all three curing regimes. As it is shown in figures 26 to 31, water tank, laboratory and outside curing regimes, in BRE and ACI for all concrete classes, the changes between the maximum and minimum amount at 7 days in BRE is 26.82% and in ACI 33.65%. It can be also concluded that at 28 days the results for BRE is 12.9% and ACI is 33.41%.

Furthermore, It could be seen that the compressive strength for the samples in water tank has significantly higher results in each class, mix designs and duration. In each class the sample that obtained the lowest results belongs to the samples that were cures outside. For example, in C16/20 for BRE samples for outside curing regime have 20.83% less compressive strength than for the water tank curing regime and in ACI this amount is 26.55%. On the other hand, this conclusion can be achieved as the amount of water loss is less than the results from other samples that were cured in water tank, therefore causing a lower result in compressive strength. Moreover, in comparison with BRE and ACI, the highest and lowest results are for the BRE mix deign. These differences were also portrayed in compressive strength, revealed in the Schmidt hammer test shown in the figures 26 to 31.

4.5.2 Flexural strength

In BRE ix design, there is a rise of 12.51% from C16/20 to C20/25 and fall of 10% in C25/30 then the amount gradually rises in water tank. There is a 7% rise from C16/20 to C20/25 then a 3% fall for the C25/30 for the Laboratory as examples throughout the concrete classes in all regimes. The same is also portrayed in ACI, for example; from C16/20 there is a 6% fall from C16/20 to C20/25 and then continuous increase to the C35/45 with the rate of 20.2% in water tank.

Similar to the precedent test, the samples obtaining highest results were water tank samples both in BRE and ACI mix designs. For instincts; for BRE C16/20, the results for the water tank, in comparison with the two other regimes, are 7% and 14.28% more than laboratory and outside. The rate for ACI is slightly higher, in the same class, 34% and 54% more than laboratory and outside.

Similar to the other tests carried out, the maximum amount of flexural strength is for the water tank curing regime samples, at 28 days for both ACI and BRE, that is 6.79 MPa in C20/25 and 6.8 MPa in C35/45 concrete classes. The minimum amount for flexural strength obtained is for the outside curing regime that is 3.85 MPa in C20/25 and 1.5 MPa in C16/20 for both BRE and ACI.

from the figure 38 and figure 39 it is shown that the average amount of flexural strength results in BRE mix design is 8.9% higher than ACI mix design. moreover, for instincts, in ACI the average strength for water tank is 16.52% more than laboratory and 22.63% more than outside curing condition.

4.5.3 Splitting Tensile strength

As it is shown in Figures 46 and 47, the ACI mix design in this study is 3.1% higher than BRE in average for the water tank curing regime, but in two other curing conditions like laboratory and outside is like the previous tests so for the laboratory in BRE mix design the average amount for this test is 3.3% higher and for the outside curing regime the average amount for this test in BRE mix design is 1.7% more than ACI mix design. In addition, for example in BRE mix design, it is determined that the average splitting tensile strength for the water tank curing is 2.9% higher than laboratory regime and 6.3% higher than outside curing regime.

In this test, the maximum and minimum amount for each test result is for to the water tank and outside curing regimes. Through all concrete classes in BRE, the maximum rate for the splitting tensile strength for C35/45 is 3.68 MPa. The minimum rate for the splitting tensile strength is 1.74 MPa for C20/25 and in ACI the maximum rate is 4.04 MPa for 40/50 and the minimum is 2.1 MPa for C20/25.

It can be concluded that the water tank cured samples are stronger than other samples in this test. For example, in C20/25 for BRE samples for outside curing regime have 21.26% less splitting tensile strength than for the water tank curing regime and in ACI this amount is 18.6%.

4.5.4 Ultrasonic Velocity Pulse

As it is clearly shown, in Figure 60 and Figure 61, almost all the UPV time in each class reaches the maximum amount when the samples were held in the outside condition. Moreover, the average amount of UPV results for BRE mix design in all water tank, laboratory and outside curing regime are higher than for ACI, 2.5% for water tank, 1.45% laboratory and 0.95% for the outside condition. For example, in

ACI mix design it could be determined that outside condition is 1.26% higher than laboratory in average amount and 4.15% higher in comparison with the water tank curing regime. It can be also concluded that the least amount is related to the water tank condition samples, whether it's made in BRE or ACI procedure. As an example, it could be said that in class C25/30 for the BRE mix design the amount of UPV time is 20.73 (1.96% more), 20.67 (1.82% more) and 19.93, and for ACI mix design it is 23 (4% more), 21.27 (0.09% more) and 21.23, which are all related to the Outside, Laboratory and Water tank.

As it is illustrated in the previous figures above, the BRE's transit time amount, in all of the curing regimes and all of the classes, descends a little until the third class, C25/30, and then starts to rise again to class C40/50. Whereas, the ACI results show opposite results, meaning that the results rise until C25/30 and then gradually decrease.

4.5.5 Schmidt Hammer

As it is shown in the figures 62 and 63, the average amount of Schmidt hammer test results in BRE are higher than in ACI mix design. From the figures above it is determined that in water tank curing condition the results for BRE are 13.14%, in laboratory are 7.32% and in outside curing regime are 7.19% higher than in ACI mix design.

4.5.6 Slump

This test has almost close results for each mix designs, the average amount for both methods are same, 49 mm. In the first two concrete classes C16/20 and C20/25 ACI method is 3.45% higher than BRE but in last two concrete classes which are C35/45 and C40/50, average amount of slump results for BRE are 3.45 higher than ACI. In this study the slump result for the C25/30 concrete class for both BRE and ACI is the same with 45 mm.

4.5.7 Entrapped Air content

The Figure 18 that is mentioned before in this chapter shows that the average of the entrapped air content for BRE and ACI are 1.31 and 1.52 which can be determined that the average amount of entrapped air content for ACI is 7.42% higher than BRE.

4.5.8 Ve-Be

The results of this test shows that the average amount for BRE method is 2.64% higher than ACI method, however, in some concrete classes in specific, the conclusion is different. For example, in class of C40/50 the Ve-Be result for the ACI is 5.45% higher than BRE method but on the other hand in the previous concrete class, C35/45 the result is different. In this concrete class the Ve-Be result for BRE is 6.94% higher than ACI mix design.

Chapter 5

CONCLUSION

The aim of this research was to study the property behavior of different concrete classes designed by two methods which are BRE and ACI under three different curing conditions. The samples produced were kept for 28 days in three conditions; water tank, laboratory and outside in open air, as stated throughout the study. These tests were accomplished in the above stated environments and the results were explained in details in the foregoing chapters. Followings are highlighted conclusions:

1- The water to cement ratio variations in concrete is significantly important for strength development. In this study, it can be seen clearly that as the water to cement ratio decreases, the strength of the concrete increases for all concrete classes.

Conclusions for each curing regime will be given below:

2- Curing in water tank: from the results, it can be concluded that all of the samples from this curing regime have the highest strength compared to all other samples from other curing regimes. For example, results showed that the average compressive strength of the BRE-samples of the all five concrete classes, at the age of 28 day, cured in water tank, were 10.21% higher than those cured in laboratory, and 18.9% higher than those cured outside. Moreover, comparing the results of the splitting tensile strength tests on water tank-cured samples with those of laboratory-cured and outdoor-cured samples,

(samples produced using ACI mix design) showed outperformance of water tank curing over the other two groups with a 9.4% and 11.11%, magnitude, respectively.

In this curing regime, the amount of water, as one of the most important elements for having high compressive strength, is constant:

3- Curing in laboratory; the strength of the samples in this curing regime are lower than the strengths of those cured in water tank, but higher than the samples cured outside in open air. Although the percentage of the variations in temperature and humidity are not consistent, like the water tank, they are also not variably high, which contributes to reducing the amount of water lost during the experiment. The range of water loss for the samples, which are kept in this curing regime, is less.

4- Curing outside (open area); the samples of this curing regime have the lowest compressive strength in comparison with those of the other two curing regimes. The alteration in temperature and humidity percentage is high, unlike the other curing regimes used. Since the samples in this curing regime faced relatively higher varied weather conditions, from two different seasons (summer and fall), the water loss, in comparison with other conditions, is high and therefore radical strength variation can be seen for the samples.

5- Moreover, there is evidence from slump test that, increase in concrete strength, corresponds to decreases in water to cement ratio, so the slump amount for concrete class decreases.

In this study, it is observed that the minimum slump was obtained from the samples of class C40/50 in both BRE and ACI method with the 33.3% and 48.7% lower than class of C16/20.

Focusing on the entrapped air content test, the results show that the minimum and maximum amounts are for C16/20 and C40/50 in both BRE and ACI mix design methods which is 20% and 13.3% as the differences.

In Ve-Be test, since it is achieved in chapter four that Ve-Be and slump test have an inverse relationship, in C16/20 it is 42.5 % less than in C40/50 for BRE samples and is 47.46 % less than for ACI samples.

UPV was explained in detail in chapter four and specified that in each concrete class and for each mix design, the maximum and the minimum transit time correspond to the outside and water tank curing regime, respectively. As an example, the ultrasonic velocity of the samples in group C16/20, BRE which were cured outdoor, was 3.12% higher than those cured in laboratory, and 4.25% greater than those cured in water tank condition, and in ACI these numbers are 0.24% and 3%, respectively.

The Schmidt hammer test was affected by the strength of the concrete class. As it rises, the Schmidt hammer grows too, and so does the compressive strength. So, it is concluded that the minimum and the maximum measured values were corresponded to C16/20 and C40/50, respectively. On the other hand, for each concrete class and both mix design methods, the highest measured amount was for the water tank curing condition and the lowest was related to the outside curing regime. For example, in C40/50 for BRE method, this amount is 1.27% higher than that of the laboratory cured samples and 2.53% greater than that of the outside cured samples; and the same results for the samples produced by ACI method is 3.1% and 2%.

During the construction of concrete it is often useful to know compressive strength at an early age so it is certainly helpful to determine this strength non-destructively which nowadays besides the UPV test, Schmidt hammer test is the most common non-destructively test method currently used for this purpose (Dalibor Kocab, Petr Misak and Petr Cikrle, et al. 2019).

In chapter four in details and earlier in this chapter, it was said that the samples which were cured in water tank had the highest amount in almost all hardened concrete test since their stabilization in temperature, humidity and water content. Likewise, the results of the compressive strength test on the 7-day age and 28-day specimens, in all concrete classes and both mix design methods, showed that this mechanical property had the highest value in the water tank cured samples, followed by the laboratory-cured and the outside cured samples, respectively.

As a numerical instance, the compressive strength of the samples in group C35/45-and-BRE, cured in water tank, was 15.11% higher than that of the laboratory-cured sample and 15.77% higher than that of the outside cured samples; And these differences were 11.58% and 17.5%, respectively for the samples produced by ACI standard. This excellence was not limited to the compressive strength only, and was observed in the flexural strength and the splitting tensile strength measured values, too. As a numerical instance, the flexural strength of the samples in group C20/25 -and-BRE, cured in water tank, was 12.7% higher than that of the laboratory-cured sample and 27.63% higher than that of the outside cured samples; And these differences were 8.93% and 18.52%, respectively for the samples produced by ACI standard.

Furthermore, the splitting tensile strength of the samples in group C20/25 -and-BRE, cured in water tank, was 9.83% higher than that of the laboratory-cured sample and 21.26% higher than that of the outside cured samples; And these differences were 8.12% and 18.6%, respectively for the samples produced by ACI standard.

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APPENDICES

Appendix A: ACI mix design method

1. Choice of slump:

Table 1: Recommended slumps for various types of constructions

Concrete construction	Slump mm	
	Maximum	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavement and slabs	75	25
Mass concrete	75	25

2. Specify the Maximum aggregate size: 20 mm

3. Approximate mixing water for Maximum aggregate size of 20 mm by the table below:

Table 2: Approximate mixing water ($\frac{\text{kg}}{m^3}$) and air content for different slumps and nominal maximum sizes of aggregates

Slump mm	Maximum aggregate size mm							
	9.5	12	20	25	40	50	75	150
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
Air content	3%	2.50%	2%	1.50%	1%	0.50%	0.30%	0.20%

4. Water to cement ratio calculation by the table below:

Table 3: Relationship between W/C ratio and compressive strength of the concrete

28 days compressive strength (Mpa)	Non- air Entered
C16/20	0.82
C20/25	0.68
C25/30	0.57
C35/45	0.48
C40/50	0.41

5. Calculation of weight of cement:

Weight of water ÷ W/C (1)

6. Volume of coarse aggregate:

Table 4: Volume of coarse aggregate per different coarse aggregates size and fineness moduli of fine aggregates

Max aggregaet size mm	Volume of Coarse aggregate						
	2.4	2.5	2.6	2.7	2.8	2.9	3
9.5	0.5	0.49	0.48	0.47	0.46	0.45	0.44
12	0.59	0.58	0.57	0.56	0.55	0.54	0.53
20	0.66	0.65	0.64	0.63	0.62	0.61	0.6
25	0.71	0.7	0.69	0.68	0.67	0.66	0.65
40	0.75	0.74	0.73	0.72	0.71	0.70	0.69
50	0.78	0.77	0.76	0.75	0.74	0.73	0.72
75	0.82	0.81	0.8	0.79	0.78	0.77	0.76
150	0.87	0.86	0.85	0.84	0.83	0.82	0.81

7. The coarse aggregate will occupy:

(Volume of the coarse aggregate)× 1.08= (#) m^3 (2)

(#) m^3 × (Dry-Rodded-unit weight) ×0.5932= (*) $\frac{kg}{m^3}$ (3)

8. Volume of fine aggregate is summation of the steps below:

8.1. Water (m^3): (water ÷ 62.4) ÷ 35.315 (4)

8.2. Cement (m^3):(Cement÷(3.15×62.4))÷35.315 (5)

8.3. Coarse aggregate:

Coarse aggregate ÷ (SSD×62.4) (6)

8.4. Air (m^3): Air (%)× 27 (7)

9. The fine aggregate will occupy:

9.1. (27 – (summation of the step 8)) ÷35.315 = Fine aggregate volume (m^3) (8)

9.2. ((Fine aggregate volume (m^3)) × (Specific gravity of fine aggregate)

×62.4) ×0.5932=surface-saturated-dry Fine aggregate (kg) (9)

Appendix B: BRE mix design method

In order to do the determine amounts of concrete making materials below table was used for BRE method of mix design.:

stage	item		Reference or calculation	Values
1	1.1	Characteristic strength	Specified	................................N/mm^2 at...............days; Proportion defective 10%
	1.2	Standard deviation	Fig. 1	.... N/mm^2 or no data .... N/mm^2
	1.3	Margin	C1	(k=1.28) 1.28 × [1.2] =...................N/mm2
			Specified	.... N/mm^2
	1.4	Target mean strength	C2	F_c + C_1 =.............N/mm^2
	1.5	Cement strength class	Specified	42.5
	1.6	Aggregate type: coarse		Crushed
		Aggregate type: fine		Crushed
	1.7	Free-water/cement ratio	Table 5, Fig. 2	.... Use the lower value ....
	1.8	Max. Free water/cement ratio	Specified	....
2	2.1	Slump or VeBe time	Specified	Slump ....mm or VeBe time.................s
	2.2	Max. Aggregate size	Specified	.........................mm
	2.3	Free-water content	Table 6	....kg/m^3
3	3.1	Cement content	C3	[2.3] + [1.7] or [1.8] =........ kg/m^3
	3.2	Maximum Cement content	Specified	.......................kg/m^3
	3.3	Minimum Cement content	Specified	.......................kg/m^3
	3.4	Modified free-water/cement ratio		.... kg/m^3
4	4.1	Relative density of aggregate (SSD)		....known/assumed
	4.2	Concrete density	Fig. 3	.... kg/m^3
	4.3	Total aggregate content	C4	[4.2] – [3.1] – [2.3] = ... kg/m^3
5	5.1	Grading of fine aggregate	Percentage passing 600 micron sieve	....%
	5.2	Proportion of fine aggregate	Fig. 4	....%
	5.3	Fine aggregate content	C5	C_4 × [5.2] = ...kg/m^3
	5.4	Coarse aggregate content	C5	C_4 –[5.3] = ...kg/m^3

Quantities	Cement	water	Fine aggregate	Coarse aggregate (kg)

	(kg)	(kg or lt)	(kg)	10 mm	20 mm	40 mm
Per m^3 (to nearest 5 kg)						
Per trial mix of ..... m^3						

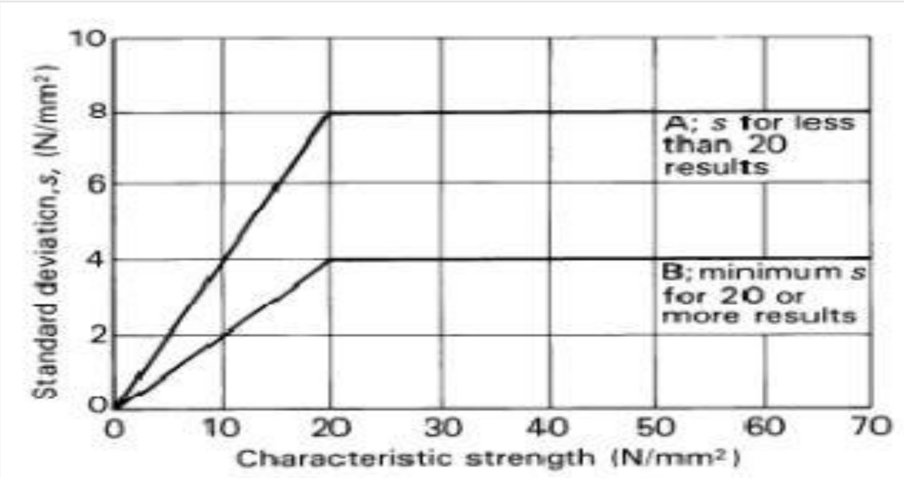

Figure 1: Relationship between standard deviation and characteristics strength

Table 5: Approximate compressive strengths (N/mm^2) of concrete mixes made with a free water/cement ratio of 0.5

Cement strength class	Type of coarse	Compressive strength (in days) (N/mm^2)			
		3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

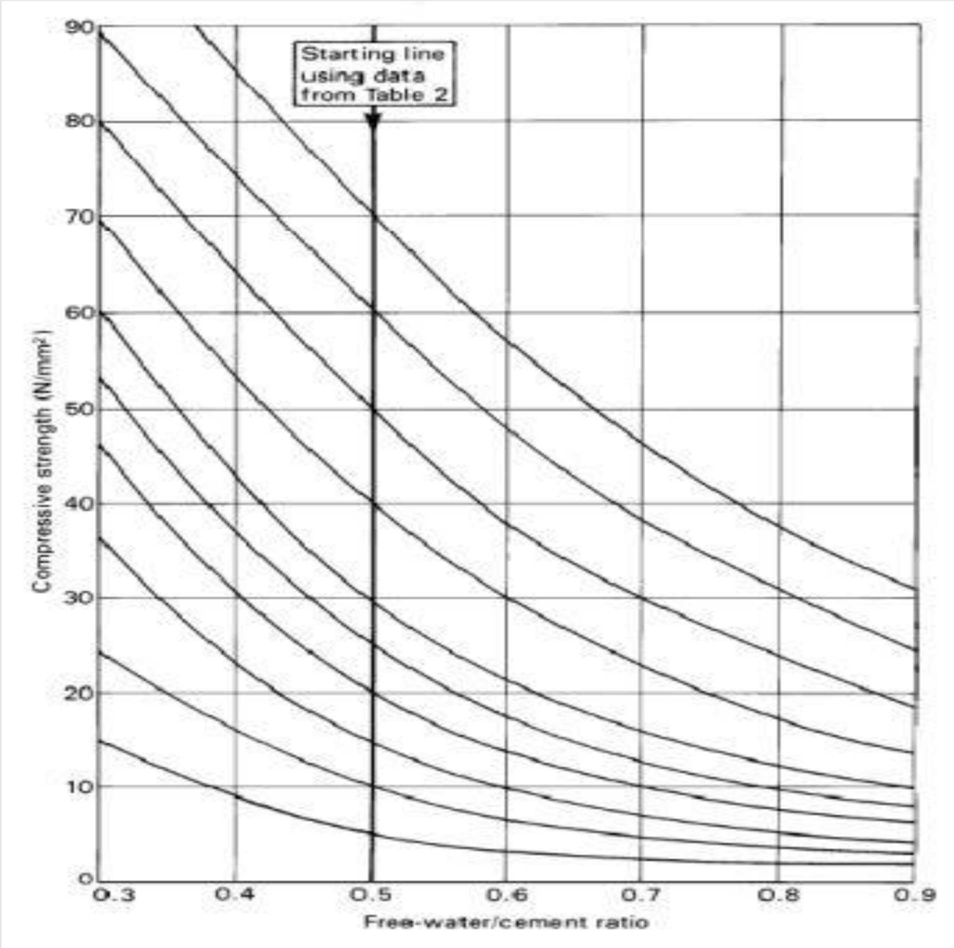

Figure 2: Relationship between compressive strength and water cement ratio

Table 6: Approximate free-water contents (kg/m^3) required to give various levels of workability

Slump mm		0-10	10-30	30-60	60-180
Max size of agg mm	Type of agg				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

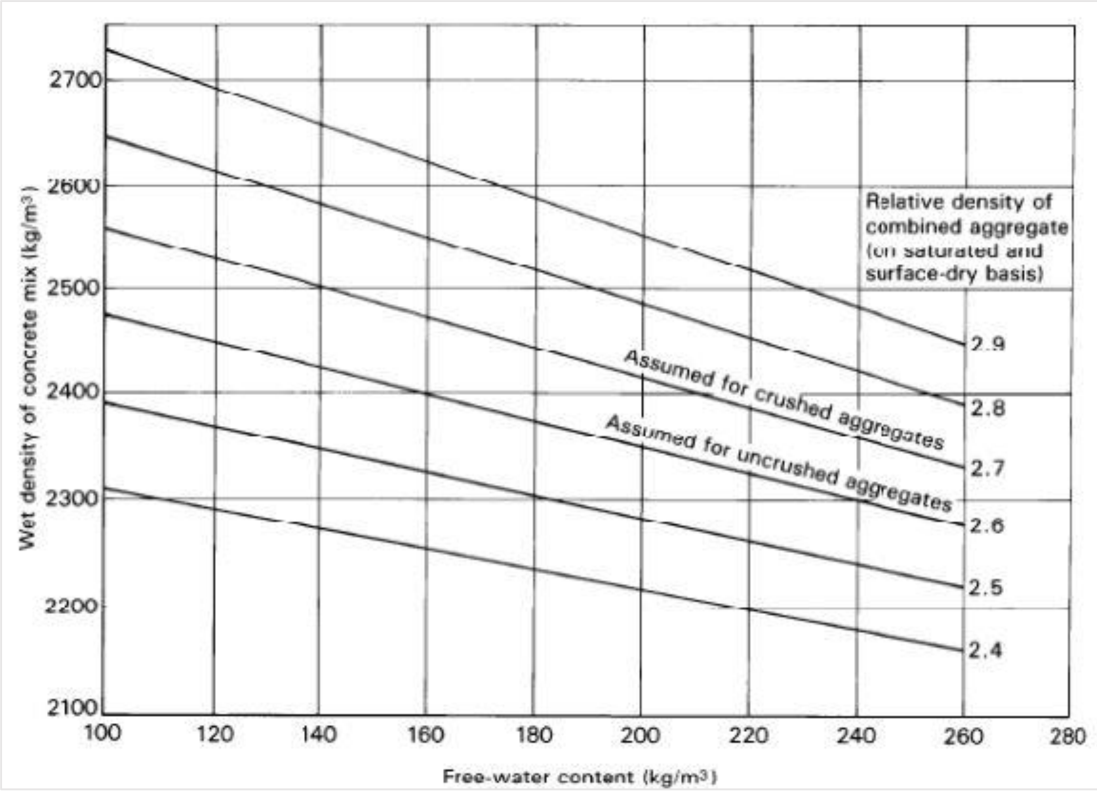

Figure 3: Estimated wet density of fully compacted concrete

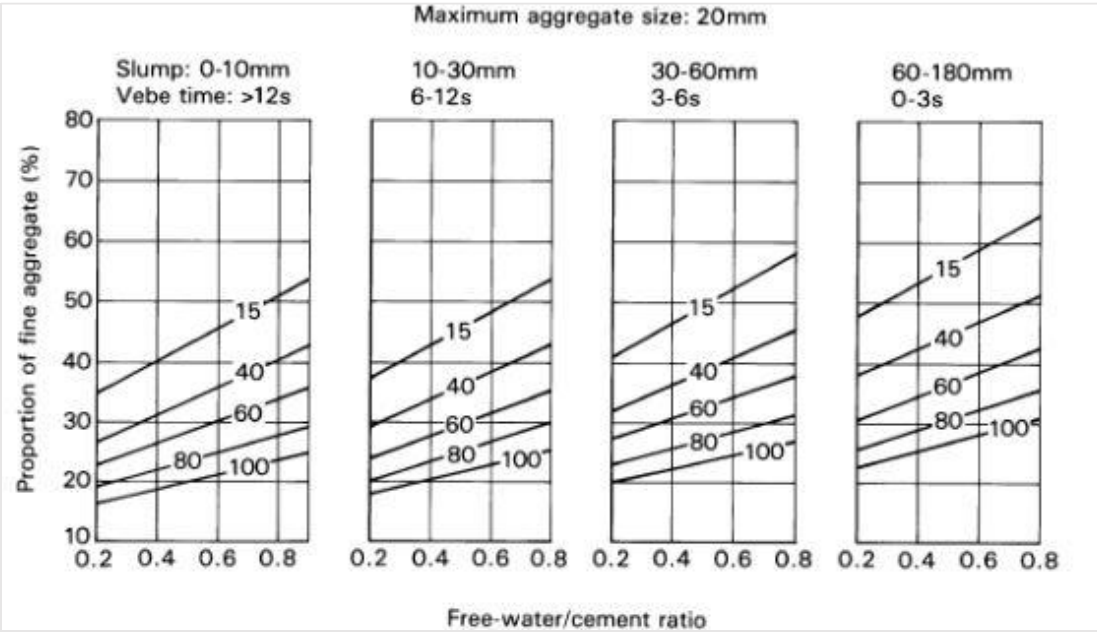

Figure 4: Recommended proportions of fine aggregate according to percentage passing a 600 µm sieve