COMPRESSIVE STRENGTH GAIN AND POROSITY REDUCTION AT DIFFERENT DAYS FOR OPC AND PCC CEMENT

MD. LATIFUR RAHMAN SIDDIQUE

MASHUKA JOARDER

REYAD MORSHED SHIHAB

DEPARTMENT OF CIVIL ENGINEERING

AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DECEMBER 2015

COMPRESSIVE STRENGTH GAIN AND POROSITY REDUCTION AT DIFFERENT DAYS FOR OPC AND PCC CEMENT

A Thesis/Project

Submitted by

Md. Latifur Rahman Siddique	Student No. 11. 02. 03. 073
Mashuka Joardar	Student No. 11. 02. 03. 076
Reyad Morshed Shihab	Student No. 11. 02. 03. 079

In partial fulfillment of the requirements for the degree of

Bachelor of Science in Civil Engineering

Under the supervision of

Dr. Enamur Rahim Latifee

Assistant Professor

Department of Civil Engineering

AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DECEMBER 2015

DEDICATION

TO OUR
PARENTS, FAMILY AND TEACHERS

DECLARATION

The work performed in this thesis for the achievement of Degree of Bachelor of Science in Civil Engineering is, Compressive Strength Gain and Porosity Reduction at Different Days for OPC and PCC Cement under the friendly supervision of Dr. Enamur Rahim Latifee.

Signature of Supervisor

____
Dr. Enamur Rahim Latifee

Signature of Authors

____

Md. Latifur Rahman Siddique

____

Mashuka Joarder

____

Reyad Morshed Shihab

ACKNOWLEDGEMENT

We wish to express our sincere gratitude to our project/thesis supervisor Dr. Enamur Rahim Latifee, Assistant Professor, Department of Civil Engineering, Ahsanullah University of Science and Technology for his invaluable suggestions, direction and supervision. His encouragement and active support was a great inspiration for carrying out the project/thesis work.

We would like to acknowledge Dr. Md. Mahmudur Rahman, Professor & Head, Department of Civil Engineering, Ahsanullah University of Science and Technology for his guidance and for giving us the opportunity to fulfill this project/thesis work.

We wish to thank to Oasis *Holdings Limited and Holcim Cement Bangladesh Ltd.* for supplying us the construction materials for completing this project/thesis work successfully.

In addition, we would like to thank all other officials of the department for their timely co-operation.

ABSTRACT

The service life and longevity of a concrete structure strongly leans on its material transport properties, such as permeability, and diffusivity which depends the micro structural characteristics of concrete. There are many properties of concrete that are allied to its durability such as absorption, strength and workability, human activities and also forces from loading that occupy a structure. It normally refers to the duration or life span of the concrete itself.

Porosity is important property that ascertains the durability of concrete and mortar. Porosity represents the amount of voids inside the concrete, which is dimensionless quantity, usually expressed as a percentage value. The aim of this study is to ascertain the effect of porosity and strength effect on mortars. The samples are tested for mortar porosity at 4 days, 7 days, 10 days, 14 days, 21 days and 28 days.

Concrete durability is directly related to porosity and compressive strength of concrete is also related to porosity. This research focuses on the strength variation of Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC) at different days as well as the porosity variation with days. The aim of this study is to ascertain the effect of porosity and its corresponding compressive strength of mortars with OPC and PCC.

The curing days for samples were 4, 7, 10, 14, 21 and 28 days for porosity test. The curing days of cement mortar sample were 3, 14, 28, 42 and 56 days for both compressive strength test and porosity test. For the cross-check of the result another casting was done for both compressive strength and porosity of 3, 7, 14, 21 and 28 days. The same trend of result has been documented as before. Another casting was done with low w/c ratio of 0.3 to observe the porous condition of mortar.. The OPC and PCC cement was used for in this experiment are CEM-I 52.5N Portland cement and CEM-II 42.5 N Portland-composite cement types respectively. This research revealed that OPC cement gains early age higher compressive strength than PCC where as PCC cement gains higher compressive strength at later age. Also, the different days-data it has been found that the strength of OPC and PCC cement, in Oven Dry (OD) condition is higher than the Saturated Surface Dry (SSD) condition. Another finding is that with the increase of the age of cube sample the porosity decreases significantly and the OPC and PCC had different trends.

TABLE OF CONTENTS

DECLARATION iii
ACKNOWLEDGEMENTS iv
ABSTRACT v
TABLE OF CONTENTS vi
LIST OF FIGURES ix
LIST OF TABLES x
LIST OF ABBREVIATIONS xi

Chapter 1 INTRODUCTION 1

2
1.1. Concrete 2
1.2 The Forms of Concrete 3
1.3 Cement 4
1.4 Pozzolanic Cement 5
1.5 Chemical Activation 5
1.6 Differences in cement types, how they tested, produced and identified 5
1.7 Standards 6
1.8 Nomenclature differences 6
1.9 Relative cost 7
1.10 Physical and chemical performances required 8
1.11 Supplementary cementing materials 8
1.11.1 Fly ash 9
1.11.2 Slag Cement 9
1.11.3 Silica fume 9
1.11.4 Aggregates 9
1.11.5 Grading 10
1.12 Shape and size matter 10

Chapter 2 REVIEW OF LITERATURE 11

2.1 Portland Cement 12
2.2 Durability 13
2.3 Pozzolonic materials 13
2.3.1 Fly ash (F.A.) 13
2.3.2 Silica fume (S.F.) 14
2.3.3 Blast furnace slag 14
2.4 Abrasion and skid resistance of an aggregate 14
2.5 Concrete Strength 14
2.6 Variation of Concrete strength 15
2.7 Concrete porosity activation 16
2.7.1 Factors affecting porosity 17

2.7.2 Chemical determination 17
2.7.3 Degree of hydration 18
2.7.4 Schematic of the rate of hydration 19
2.7.5 Diffusion process 20-22
2.7.6 Air content 23
2.8 Measurements of air content in concrete 23
2.8.1 Pressure Method 24
2.8.2 Volumetric Method 24
2.8.3 Gravimetric Method 25
2.8.4 Chace air indicator 25
2.8.5 Air-Void system 26
2.9 Consolidation 26-27
2.9.1 External board vibrator 28
2.9.2 External rotary vibrator 28
2.10 Admixture of concrete 29
2.10.1 Effectiveness of admixture 29
2.11 Functions 30
2.11.1 Water reducing admixtures 30
2.11.2 Retarding admixtures 30
2.11.3 Accelerating admixtures 30
2.11.4 Super plasticizer 31
2.11.5 Corrosion-inhibiting admixtures 31
2.12 Effect on permeability 31
2.13 Effect on shrinkage 31
2.14 Effect on workability 32

Chapter 3 METHODOLOGY 33

3.1 Materials collections and properties 34
3.1.1 Cement 34
3.1.2 Sand 35
3.1.3 Water 36
3.2 Physical properties determination of material 36
3.2.1 Sieve analysis of fine aggregate 36
3.2.2 Specific Capacity and absorption capacity of fine aggregate 37-40

3.3 Material Mix proportion and mortar sample 40
3.4 Compressive strength test 40
3.5 Preparation of cube specimen 41
3.6 Equipments and machine 42-44

Chapter 4 EXPERIMENTAL WORK 45

4.1 Materials 46
4.1.1 Graded standard sand 46
4.2 Temperature and humidity 46
4.3 Test Specimen 46
4.4 Preparation of specimen molds 47
4.5 Mix Design 47
4.6 Sieve Analysis 48
4.7 Procedure 49
4.7.1 Composition of mortars 49
4.7.2 Preparation of mortars 50
4.7.3 Determination of Flow 50
4.7.4 Molding test specimen 50-53
4.7.5 Storage of test specimen 54
4.7.6 Determination of compressive strength 55
4.7.7 Porosity test

Chapter 5 RESULTS AND DISCUSSION 56

5.1 Compressive strength and porosity analysis 57

5.1.1 Porosity (Case-1: PCC Cement Mortar and porosity determination by keeping the samples on air) 57-60
5.1.2 Compressive strength (Case-1 : Compressive strength determined for OPC and PCC cement mortar for Oven dry and Saturated surface dry condition) 61-64
5.1.3 Porosity (Case-2: OPC and PCC Cement Mortar and porosity determination by keeping the samples on air) 64
5.1.4 Compressive Strength (Case-2: Compressive strength determined for OPC and PCC cement mortar for Saturated surface dry condition) 65
5.1.5 Porosity (Case-3 : OPC and PCC Cement Mortar and porosity determination by keeping the samples into water) 66-67
5.1.6 Porosity (Case-4: OPC and PCC cement mortar and porosity determined by 5 hour boiling) 68-69

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS 70

6.1 Conclusions 71
6.2 Recommendations 71

REFERENCES 72-73

APPENDIX A : Experimental Images 74

LIST OF FIGURES

Figure no. Description	Page
Fig. 1.1 Effect of fly ash content and age on strength development of concrete	4
Fig. 1.2 Schematic illustration of free $Ca(OH)_2$ content in Portland and pozzolana cement.	4
Fig. 2.1 Schematic of the rate of hydration or heat evolution as a function of time.	19
Fig. 2.2 Results of a realistic digital model of cement hydration.	21
Fig. 2.3 Typical development of the degree of hydration and compressive strength of a Type I Port land cement over time.	22
Fig. 2.4 $CaCl_2$ increases drying shrinkage of concrete, although the moisture content is decreased	32
Fig. 4.1 Order of Tamping in Molding of Test Specimens	49
Fig. 5.1 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-1)	58
Fig. 5.2 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-2)	58
Fig. 5.3 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-3)	59
Fig. 5.4 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-4)	59
Fig. 5.5 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-5)	60
Fig. 5.6 Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-6)	60
Fig. 5.7 Strength at different days in OD and SSD condition for OPC cement	61
Fig. 5.8 Strength at different days in OD and SSD condition for CPC cement	62
Fig. 5.9 Strength at different days in OD condition for OPC and PCC cement	63
Fig. 5.10 Strength at different days in SSD condition for OPC and PCC cement	63
Fig. 5.11 Porosity at different days for OPC PCC cement Mortar	64

Fig. 5.12 Strength at Different days in SSD condition for OPC & PCC Cement 65
Fig. 5.13 Porosity variation with corresponding compressive strength for PCC Cement Mortar 66
Fig. 5.14 Porosity variation with corresponding compressive strength for OPC Cement Mortar 67
Fig. 5.15 Porosity Variation between OPC and PCC cement for normal sample porosity and 5 hour boiled sample. 68
Fig. 5.16 Porosity variation between normal sample and 5 hour boiled sample for OPC cement. 69
Fig. 5.17 Porosity variation between normal sample and 5 hour boiled sample for PCC 68

LIST OF TABLES

Table no.	Description	Page
Table 3.1	Chemical composition for CEM I (OPC Cement)	34
Table 3.2	Physical properties for CEM I (PCC Cement)	34
Table 3.3	Chemical composition for CEM II/B	35
Table 3.4	Physical properties for CEM II/B	35
Table 3.5	Permissible Variations of Specimen Molds	42
Table 4.1	Sieve Analysis	48
Table 4.2	Precision	52
Table 5.1	Data for Porosity test	57
Table 5.2	Data Table	60
Table 5.3	Strength at different days of Cement mortar for OPC and PCC cement	65
Table 5.4	Compressive strength and corresponding Percent of Porosity for different days of OPC and PCC cement	66

ABBREVIATIONS

PCC = Portland Composite Cement

OPC = Ordinary Portland Cement

SSD = Saturated-surface-dry

OD = Oven dry

W_{SSD} = Weight of Materials in SSD condition

W_{OD} = Weight of Materials in OD condition

W_{Water} = Weight of Materials submerging into water.

Chapter One

INTRODUCTION

1.1. Concrete :

Concrete is easy to work with, versatile, durable, and economical. By observing a few basic precautions, it is also safe-one of the safest building materials known. Over the years, relatively few people involved in mixing, handling, and finishing concrete have experienced injury. Outlined below are some simple suggestions-protection, prevention, common sense precautions-useful to anyone working with portland cement and concrete.

Concrete is a mixture of paste and aggregates. The paste, composed of portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. Within this process lies the key to a remarkable trait of concrete: it's plastic and malleable when newly mixed, strong and durable when hardened.

Concrete’s durability, strength and relatively low cost make it the backbone of buildings and infrastructure worldwide—houses, schools and hospitals as well as airports, bridges, highways and rail systems. The most-produced material on Earth will only be more in demand as, for example, developing nations become increasingly urban, extreme weather events necessitate more durable building materials and the price of other infrastructure materials continues to rise.

Even construction professionals sometimes incorrectly use the terms cement and concrete interchangeably. Cement is actually an ingredient of concrete. It is the fine powder that, when mixed with water, sand, and gravel or crushed stone (fine and coarse aggregate), forms the rock-like mass known as concrete.

1.2. The Forms of Concrete

Concrete is produced in four basic forms, each with unique applications and properties.

1. Ready-mixed concrete, far the most common form, accounts for nearly three-fourths of all concrete. It's batched at local plants for delivery in the familiar trucks with revolving drums.
2. Precast concrete products are cast in a factory setting. These products benefit from tight quality control achievable at a production plant. Precast products range from concrete bricks and paving stones to bridge girders, structural components, and wall panels. Concrete masonry another type of manufactured concrete, may be best known for its conventional 8-by-8-by-16-inch block. Today's masonry units can be molded into a wealth of shapes, configurations,

colors, and textures to serve an infinite spectrum of building applications and architectural needs.

3. Cement-based materials represent products that defy the label of "concrete," yet share many of its qualities. Conventional materials in this category include mortar, grout, and terrazzo. soil-cement and roller-compacted concrete — "cousins" of concrete—are used for pavements and dams. Other products in this category include flowable fill and cement-treated bases.
4. A new generation of advanced products incorporates fibers and special aggregate to create roofing tiles, shake shingles, lap siding, and countertops

1.3. Cement :

Cement is the most widely used construction material throughout the world. This leads to an enormous production of cement to meet the increasing demand for housing and infrastructure. Cement production is however harmful on the environment due to carbon dioxide emission. Reducing cement production while maintaining sustainable development has been an important issue in the development of construction materials. Replacing Portland cement with percentages of pozzolana has been reported as a good alternative.

Each year, the concrete industry produces about 12 billion tonnes of concrete and uses about 2.86 billion tonnes of Portland cement worldwide (Global Cement Report, 2010). Indeed, with the manufacture of one tonne of cement, approximately 0.8 tonne of CO_2 are released into the atmosphere. About 50% of the CO_2 produced during cement manufacture is due to fossil fuel consumption and the rest due to the calcination of the limestone (Claus and Guimaraes, 2007). The cement industry accounts for 5 – 8% of global CO_2 emission. This makes the cement industry the second largest producer of this greenhouse gas (Scrivener and Kirk, 2007). Also the SO_3 and NO_x released as a result of Portland cement manufacture can cause serious environmental impact such as greenhouse effect and acid rain (Dongxu et al, 2000).

It is obvious that minimization of production of Portland cement clinker would greatly help to reduce the CO_2 emission produced by the cement industry. One wise solution is to promote the usage of pozzolanic materials in mortar and concrete works thereby reducing the world‘s demand for Portland cement which eventually reduces the emission of CO_2 into the atmosphere.

1.4. Pozzolanic Cement

Pozzolanic materials when used in mortar and concrete works improve durability which is the ability of concrete to resist weathering action, chemical attack and abrasion. Pozzolanic materials also bring in other technical advantages such as low heat of hydration and high ultimate strength. The higher strength of concrete with pozzolanas at later ages is as a result of the pozzolanic reactions increasing the amount of calcium silicate hydrates (C-S-H) while diminishing $Ca(OH)_2$ (Helmuth, 1987)

That notwithstanding, pozzolana cements are noted for their slow strength development resulting in low early strengths as shown in Figure 1.1. For replacement level up to 30%, the strength at ages about 3 to 6 months will often exceed that of Portland cement concrete.

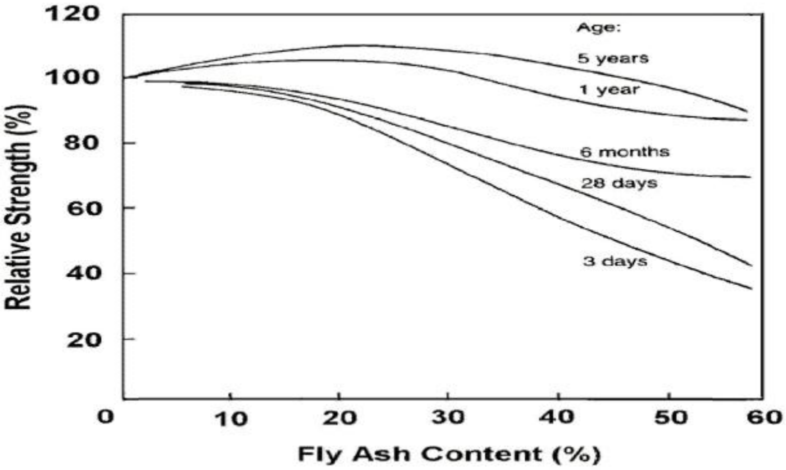


Figure 1.1: Effect of fly ash content and age on strength development of concrete (Source: Neville, A. M., 1981)

They also exhibit slow rate of setting and hardening. These undesirable properties rise from the slow reaction rate of the active pozzolana constituents with the liberated $Ca(OH)_2$ from the Portland cement (Lea, 1970a). It is estimated that the extent of reaction of pozzolana is only about 20% at 90 days, compared with 80% for Portland cement (Shi, 2001). Due to the pozzolanic reactions between lime and constituents of pozzolana, the free lime content in pozzolana cement or concrete decreases with time (Fig. 1.2) depending on the content and nature of the pozzolana in the cement and concrete.

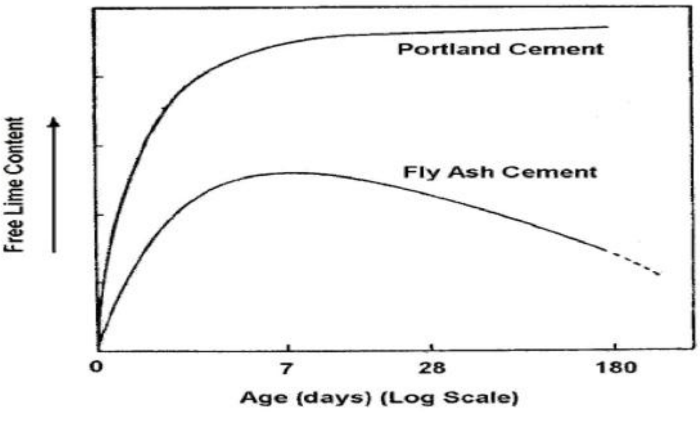


Figure 1.2: Schematic illustration of free $Ca(OH)_2$ content in Portland and pozzolana cement. (Source: Shi and Shao, 2002)

Early strength is a critical measure in concrete industry since it determines the speed of construction. Therefore, low early strength development is an obstacle in promoting pozzolana usage as Portland cement replacement. In order to overcome slow early strength development and high setting times in pozzolanic materials, techniques such as thermal activation, mechanical activation and chemical activation have been proposed in literature.

Mechanical activation (prolonged grinding) can increase the reactivity of pozzolana to some extent. Grinding, however, is an energy intensive process and needs complicated facilities. Spherical pozzolana particles are broken during grinding, which will result in higher water demand for a given workability and thus somewhat offset the improvements in reactivity due to grinding (Shi and Shao, 2002). Also, elevated temperature curing increases the strength development rate, but decreases the ultimate strength of concrete (Shi and Shao, 2002) and could be very expensive.

A comparison based on strength-cost relationship indicates that the addition of chemical activators into concrete and mortar mixtures is the most simple, efficient and inexpensive technique for enhancing reactivity of pozzolana cement (Shi and Day, 2001).

1.5. Chemical activation :

This study seeks to investigate how the setting time and early strength of pozzolana cements can be improved by the application of chemical activators such as $CaCl_2$, Na_2SO_4, and $AlCl_3$. In chemical activation, the pozzolana cement is treated with a chemical compound solution before the mortar or concrete is prepared. The chemical compound, as a separate ingredient, can also be dissolved in the water to be used to prepare the mortar or concrete.

Construction documents often specify a cement type based on the required performance of the concrete or the placement conditions. Certain cement manufacturing plants only produce certain types of portland cement.

1.6. What are the differences in these cement types and how are they tested, produced, and identified in practice?

In the most general sense, portland cement is produced by heating sources of lime, iron, silica, and alumina to clinkering temperature (2,500 to 2,800 degrees Fahrenheit) in a rotating kiln, then grinding the clinker to a fine powder. The heating that occurs in the kiln transforms the raw materials into new chemical compounds. Therefore, the chemical composition of the cement is defined by the mass percentages and composition of the raw sources of lime, iron, silica, and alumina as well as the temperature and duration of heating. It is this variation in raw materials source and the plant-specific characteristics, as well as the finishing processes (i.e. grinding and possible blending with gypsum, limestone, or supplementary cementing materials), that define the cement produced.

1.7. Standards

To ensure a level of consistency between cement-producing plants, certain chemical and physical limits are placed on cements. These chemical limits are defined by a variety of standards and specifications. For instance, portland cements and blended hydraulic cements for concrete in the U.S. conform to the American Society for Testing and Materials (ASTM) C150 (Standard Specification for Portland Cement), C595 (Standard Specification for Blended Hydraulic Cement) or C1157 (Performance Specification for Hydraulic Cements).

Some state agencies refer to very similar specifications: AASHTO M 85 for portland cement and M 240 for blended cements. These specifications refer to standard test methods to assure that the testing is performed in the same manner. For example, ASTM C109 (Standard Test Method for Compressive Strength for Hydraulic Cement Mortars using 2-inch Cube Specimens), describes in detail how to fabricate and test mortar cubes for compressive strength testing in a standardized fashion.

1.8. Nomenclature Differences

In the US, three separate standards may apply depending on the category of cement. For portland cement types, ASTM C150 describes:

Cement Type	**Description**
Type I	Normal
Type II	Moderate Sulfate Resistance
Type II (MH)	Moderate Heat of Hydration (and Moderate Sulfate Resistance)
Type III	High Early Strength
Type IV	Low Heat Hydration
Type V	High Sulfate Resistance

For blended hydraulic cements – specified by ASTM C595 – the following nomenclature is used:

Cement Type	**Description**
Type IL	Portland-Limestone Cement
Type IS	Portland-Slag Cement
Type IP	Portland-Pozzonlan Cement
Type IT	Ternary Blended Cement

In addition, some blended cements have special performance properties verified by additional testing. These are designated by letters in parentheses following the cement type. For example Type IP(MS) is a portland-pozzolan cement with moderate sulfate resistance properties. Other special properties are designated by (HS), for high sulfate resistance; (A), for air-entraining cements; (MH) for moderate heat of hydration; and (LH) for low heat of hydration. Refer to ASTM C595 for more detail.

However, with an interest in the industry for performance-based specifications, ASTM C1157 describes cements by their performance attributes:

Cement	Type	Description
Type	GU	General Use
Type	HE	High Early-Strength
Type	MS	Moderate Sulfate Resistance
Type	HS	High Sulfate Resistance
Type	MH	Moderate Heat of Hydration
Type	LH	Low Heat of Hydration

Note: For a thorough review of US cement types and their characteristics see PCA's *Design and Control of Concrete Mixtures*, EB001 or *Effect of Cement Characteristics on Concrete Properties*, EB226.

1.9. Relative Cost

There is an inherent desire by most people to own decent and affordable houses. On average, the cost of building materials for a housing structure comprises about 50 percent of the total cost of the building (Jones and Dhir, 2000). For lower income shelters this percentage could rise to as much as 80 percent depending on the country where the construction occurs (Laban and Benedetti, 2002; Jones and Dhir, 2000). The high cost is normally attributed to the high prices of cement. A majority of the citizens in developing countries, especially where the Government do not have an established housing and shelter system, cannot afford the cement, which is a major building binder for housing and construction in general (Muthengia, 2008). This has lead to the mushrooming of slums such as Kibera in Nairobi-Kenya. There is an increasing demand for decent housing as the shanty houses poses various health challenges (Ghebreyesus *et al*., 2000).

The cost of construction materials is increasing day by day because of high demand, scarcity of raw materials and high price of energy. Portland cement is the most common type of cement used in construction. It is an expensive binder due to the high cost of production associated with the high energy requirements of its manufacturing process (Neville, 1995). From the standpoint of energy saving and environmental conservation, the use of alternative constituents in construction materials is now a global concern.

Other relatively low cost materials with cementitious properties are natural pozzolana such as volcanic tuff, clay and waste products from industrial plants such as slag, fly ash and silica fume. They can be used as a partial replacement for Portland cement to make blended cements. In addition, to reduce the cost of binder, there are potential technological benefits from the use of pozzolanic materials as those blended with Portland cement in concrete applications. These include decreased permeability of aggressive ions and increased ultimate strength and durability of concrete. These benefits have lead to an increased demand for pozzolanic materials for use in making pozzolanic cements..

1.10. Physical and Chemical Performance Requirements

Chemical tests verify the content and composition of cement,while physical testing demonstrates physical criteria.

In C150/M 85 and C595/M 240, both chemical and physical properties are limited. In C1157, the limits are almost entirely physical requirements.

Chemical testing includes oxide analyses (SiO_2, CaO, Al_2O_3, Fe_2O_3, etc.) to allow the cement Case composition to be calculated. Type II cements are limited in C150/M 85 to a maximum of 8 percent by mass of tricalcium aluminate (a cement Case, often abbreviated C_3A), which impacts a cement's sulfate resistance. Certain oxides are also themselves limited by specifications: For example, the magnesia (MgO) content which is limited to 6 percent maximum by weight for portland cements, because it can impact soundness at higher levels.

Typical physical requirements for cements are: air content, fineness, expansion, strength, heat of hydration, and setting time. Most of these physical tests are carried out using mortar or paste created from the cement. This testing confirms that a cement has the ability to perform well in concrete; however, the performance of concrete in the field is determined by all of the concrete ingredients, their quantity, as well as the environment, and the handling and placing procedures used.

Although the process for cement manufacture is relatively similar across North America and much of the globe, the reference to cement specifications can be different depending on the jurisdiction. In addition, test methods can vary as well, so that compressive strength requirements (for example) in Europe don't 'translate' directly to those in North America. When ordering concrete for construction projects, work with a local concrete producer to verify that cement meeting the requirements for the project environment and application is used, and one that meets the appropriate cement specification.

1.11. Supplementary Cementing Materials:

Supplementary cementing materials (SCMs) contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are fly ashes, slag cement (ground, granulated blast-furnace slag), and silica fume. These can be used individually with portland or blended cement or in different combinations. Supplementary cementing materials are often added to concrete to make concrete mixtures more economical, reduce permeability, increase strength, or influence other concrete properties.

1.11.1 Fly ash

The most commonly used pozzolan in concrete, is a by-product of thermal power generating stations. Commercially available fly ash is a finely divided residue that results from the combustion of pulverized coal and is carried from the combustion chamber of the furnace by exhaust gases.

1.11.2 Slag Cement

Formerly referred to as ground, granulated blast-furnace slag, is a glassy, granular material formed when molten, iron blast-furnace slag is rapidly chilled - typically by water sprays or immersion in water - and subsequently ground to cement fineness. Slag cement is hydraulic and can be added to cement as an SCM.

1.11.3 Silica fume

Also called condensed silica fume or microsilica, is a finely divided residue resulting from the production of elemental silicon or ferro-silicon alloys that is carried from the furnace by the exhaust gases. Silica fume, with or without fly ash or slag, is often used to make high-strength concrete.

1.11.4 Aggregates :

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories--fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch sieve. Coarse aggregates are any particles greater than 0.19 inch, but generally range between 3/8 and 1.5 inches in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular subbases, soil-cement, and in new concrete.

After harvesting, aggregate is processed: crushed, screened, and washed to obtain proper cleanliness and gradation. If necessary, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality. Once processed, the aggregates are handled and stored to minimize segregation and degradation and prevent contamination.

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered include:

- grading
- durability
- particle shape and surface texture
- abrasion and skid resistance
- unit weights and voids
- absorption and surface moisture

1.11.5 Grading

It refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

1.12 Shape and Size Matter

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete.

Chapter 2

LITERATURE REVIEW

2.1 Portland Cement

Cement is defined as a powdered material that chemically reacts with water and therefore attains the property of setting and hardening (Neville, 1996). This property makes the cement hydraulic. Portland cement is made by heating raw materials with an appropriate chemistry, usually mixture of limestone and clay, to a temperature between 1400^{o}C and 1600^{o}C, where the two materials interact chemically to form the calcium silicates. Partial fusion occurs, and nodules of clinker are produced. The clinker is mixed with a few percent of calcium sulphate and finely ground, to make the cement.

Limestone + Clay → Clinker + 2%gypsum → Portland cement

Some modern cement specifications, EN 197-1, also permit adding up to 5% limestone in the course of clinker grinding. The calcium sulphate, which is commonly described as gypsum, controls the rate of set and influences the rate of strength development. The clinker chemically has a composition of CaO, SiO_2, Al_2O_3, and Fe_2O_3, all constituting about 80% of Portland cement. The other significant minor oxides are MgO, SO_3, K_2O and Na_2O (Lea, 1970). Cement clinker particles are multiCase solids. Each Case has a specific reaction with water to produce a range of hydration products.

Alite (C_3S) is the most important constituent of all normal Portland cement clinkers and it constituents 50-70% of the total composition of the clinker. It is tricalcium silicate (Ca_3SiO_5) modified in composition and crystal structure by ionic substitutions. It reacts relatively quickly with water, and is the most important of the constituent Cases for strength development up to 28 days. Belite (C_2S) constitutes 15-30% of normal Portland cement clinkers. It is dicalcium silicate (Ca_2SiO_4) and normally presents wholly or largely as β polymorph. It reacts slowly with water, thus contributing later-age strength beyond 28 days (Taylor, 1997).

Aluminate constitutes 5-10% of most normal Portland cement clinkers. It is tricalcium aluminate ($3CaO.Al_2O_3$), substantially modified in composition and sometimes also in structure by ionic substitutions. It reacts rapidly with water, and can cause undesirably rapid setting unless a set-controlling agent, such as gypsum, is added (Taylor, 1997).
Ferrite makes up 5-15% of normal Portland cement clinkers. It is tetracalcium aluminoferrite (Ca_2AlFeO_5), substantially modified in composition by variation in Al/Fe ratio and ionic substitutions. The rate at which it reacts with water appears to be somewhat variable, perhaps due to differences in composition or other characteristics, but in general is high initially and low or very low at 28 days (Taylor, 1997). Table 2.3 shows the compositions of Cases in Portland cement clinker.

2.2 Durability

It is the capacity of concrete to resist deterioration caused by environment, human activities and also forces from loading that occupy a structure. It normally refers to the duration or life span of the concrete itself. The service life and durability of a concrete structure strongly depend on its material transport properties, such as permeability, sorptivity, and diffusivity which are controlled by the microstructural characteristics of concrete [1]. There are many properties of concrete that is related to its durability such as absorption, strength and workability. It is known that the porosity is the critical components of the microstructure of hydrated cement paste that influence durability.

Porosity is the volume of voids that occupy a concrete. In order to achieve high strength, low permeability, and durable concrete, it is therefore necessary to reduce the porosity of cement paste [2]. Mortar are basically consists of cement, sand, water and additional material, known as an admixture added to modify certain of its properties. It is well known that the incorporation of pozzolanic materials as partial replacement of cement refines the porosity of the paste. Mortars with pozzolan replacement are known as modified cement mortar. Various types of pozzolanic materials have been used in the construction industry to produce mortar or concrete to reduce the use of OPC for a long time [3].

2.3 Pozzolanic materials :

They are consist of either natural (Trass, zeolite, metakaolinite, burned clay) or artificial (silica fume, fly ash, blast furnace slag) types [4]. The use of additional cementitious materials due to economic, technical and environmental considerations has become common practice in modern concrete construction industry [5, 6].

The use of pozzolanic materials as a replacement addition to cement in production is useful for a number of purposes. This is reduces concrete production cost and also reduce high energy consumption as the production of OPC usually needs lots of energy [7]. One of factors that related to the strength of concrete is fundamentally a function of the volume of voids in it. Usually, the higher amount of voids in the concrete, the less strength it will exhibit. In addition, the curing condition also may affect the strength of the mortar or concrete. “Strictly speaking, strength of concrete is influenced by the volume of all voids in concrete: entrapped air, capillary pores, gel pores, and entrained air, if present [8]”.

Much of the researches have been conducted on the durability and strength of concrete made
with mineral admixtures [9-12].

2.3.1 Fly ash (FA)

It is waste materials from the thermal power plant. Fly ash is known to be a good pozzolanic material for use in concrete [3]. According to ASTM C618-85 [13], there are two basic types of FA: Class F (low-calcium FA) and Class C (high-calcium FA).

Its physical and chemical properties depend exclusively on the quality of coal used and on technological conditions of burning. FA is added to Portland cement (PC) or directly to mortars or concretes [14].

2.3.2 Silica fume (SF)

It is a by-product resulting from the reduction of high-purity quartz with coal in electric arc furnaces [15]. It has been observed that the presence of such particles can reduce the positive effect of the SF on the microstructure and mechanical properties of the mortars [16, 17]. The use of SF decreases the permeability, thereby increasing the resistance of concrete against corrosion [18, 19], improving its strength and durability [20, 21]. The advantages of SF caused SF being the most well-known additive material for high strength concrete in recent years.

2.3.3 Blast furnace slag

It is a nonmetallic coproduct produced in the process. It consists primarily of silicates, aluminosilicates, and calcium-alumina-silicates. The molten slag, which absorbs much of the sulfur from the charge, comprises about 20 percent by mass of iron production.

The void content between particles affects the amount of cement paste required for the mix. Angular aggregates increase the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content. Absorption and surface moisture of aggregate are measured when selecting aggregate because the internal structure of aggregate is made up of solid material and voids that may or may not contain water. The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate.

2.4 Abrasion and skid resistance of an aggregate

They are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

Cement is the major industrial commodity That is commercially manufactured in over 120 countries Mixed with aggregates and water Cement forms the ubiquitous concrete which is used in constructions.

2.5 Concrete Strength

Strength is usually the basis for acceptance or rejection of the concrete in the structure. The specifications or code designate the strength (nearly always compressive) required of the concrete in the several parts of the structure. In those cases in which strength specimens fail to reach the required value, further testing of the concrete in place is usually specified. This may involve drilling cores from the structure or testing with certain nondestructive instruments that measure the hardness of the concrete. Strength is necessary when computing a proposed mix for concrete, as the contemplated mix proportions are based on the expected strength-making properties of the constituent.

The methods and technology for producing high strength concrete are not basically different from those required for concrete of normal grade except that the emphasis on quality control is perhaps greater with High strength concrete. High strength concrete can be produced with all of the cements and cement replacements normally available in Singapore, including Portland cement, sulfate-resisting Portland cement, and combinations with pulverised fuel ash and ground granulated blast furnace, silica fume slag. High early strength cements should preferably be avoided as a rapid rise in hydration temperature may cause problems of (internal) cracks or micro-cracks due to the higher cementitious material content. The porosity (i.e. the volumetric proportion of voids) of concrete has been used extensively for the prediction of the properties of concrete.

2.6 Variation of concrete strength

The strength activity index with portland cement is not to be considered a measure of the compressive strength of concrete containing the fly ash or natural pozzolan. The mass of fly ash or natural pozzolan specified for the test to determine the strength activity index with portland cement is not considered to be the proportion recommended for the concrete to be used in the work. The optimum amount of fly ash or natural pozzolan for any specific project is determined by the required properties of the concrete and other constituents of the concrete and is to be established by testing. Strength activity index with portland cement is a measure of reactivity with a given cement and is subject to variation depending on the source of both the fly ash or natural pozzolan and the cement.

Thus the use of high volume fly ash in concrete has recently gained popularity as a resource-efficient, durable, cost-effective, sustainable option for ordinary portland cement (OPC) concrete applications

So It is not possible to design a concrete mix of high strength with cement of low strength. The variation in strength of cement is due largely to the lack of uniformity in the raw materials used in its manufacture, not only between different source of supply, but also with in a quarry. Further, differences in details of the process of manufacture and above all, the variation in the ash content of coal used to fire the kilin, contribute to the variation in the properties of commercial cements . Portland composite cement is a hydraulic binder. It is produced by grinding clinker and a certain amount of gypsum, fly ash, slag and limestone.

Due to variation of cement strength, the concrete made from these cement will also have variable strength. For a correct approach in the Concrete Mix Design, if the facilities at site are available, with the given set of materials, requirements and site conditions own W/C ratio v/s compressive strength of concrete curve should be developed at site itself.

It is often observed that cement bags marked as OPC Grade may really be containing cement of much higher grade. PPC cement as per IS Code is only of 33 Grade. Where as on bags it is marked as 43 MPa or 53 MPa. Site cement samples should be tested for its actual strength and other properties. There are instances where higher grade cement is being used even for low strength concrete, as mortar or even for plastering. This can lead to unnecessary cracking of concrete/surfaces.

In low grade OPC, the gain in strength will continue beyond 28th day. Due to early strength gain of higher grade of OPC the concrete strength do not increase much beyond 28th day. The heat of hydration of higher grade OPC being higher, the chances of micro-cracking of concrete is much greater. Thus during initial setting period of concrete, the higher head of hydration can lead to damaging micro-cracking with in the concrete which may not be visible at surface. The situation can be worse when we tend to increase the quantity of the cement in concrete with a belief that such increase are better for both strength and durability of concrete.

Concrete durability-related properties are known to be negatively affected due to expansions that result from factors such as freezing and thawing actions, alkali-aggregate reactions, sulfate attack, corrosion of the reinforcement, etc. Such expansions depend, to a large extent, upon ingress of water, gases, and aggressive chemicals into the concrete; which, in turn, depend upon permeability (which depend upon porosity). Therefore, permeability of concrete can be used as a measure of concrete durability. Porous concrete used in place of conventional concrete decreases the total amount of runoff leaving a site, promotes infiltration of runoff into the ground, reduces the amount of pollutants carried to a storm drain or waterway, and aids with reducing peak runoff velocity and volume. porosity affects can be related to concrete durability.

2.7 Concrete Porosity Activation

Porous concrete is used in place of conventional concrete decreases the total amount of runoff leaving a site, promotes infiltration of runoff into the ground, reduces the amount of pollutants carried to a storm drain or waterway, and aids with reducing peak runoff velocity and volume.

Developing land for residential, commercial and industrial use carries the detrimental effect of vastly increasing the amount of impervious surface area as land is paved to create roads and parking lots. During a storm, runoff flows over impervious pavement, picking up pollutants such as dirt, grease and oil, and transports these contaminants to streams and storm sewer systems.

In response to this issue, designers developed porous paving systems that allow runoff to pass through the pavement into a stone reservoir, before infiltrating the soil below to recharge the groundwater supply. With proper installation and maintenance, porous paving allows for infiltration of up to 80% of annual runoff volume.

Additionally, studies indicate that porous concrete systems can remove up to 65% of undissolved nutrients from runoff and up to 95% of sediment in runoff.

The design for application of porous concrete consists of at least three layers: a two to four-inch layer of porous concrete, a one to two- inch filter layer of half-inch crushed aggregate, a 12- inch minimum reservoir layer of one to three-inch aggregate, and an optional layer of filter fabric. Porous concrete consists of a mix including Portland cement, uniform open-graded coarse aggregate, and water. The void space of porous concrete ranges between 15% and 22%, compared to a three to five percent void space in conventional concrete. The concrete itself provides for some pretreatment of runoff. The crushed aggregate filter layer aids with removing some pollutants. Runoff is stored in the reservoir bed, a highly permeable layer of open-graded clean-washed aggregate with at least 40% void space. The filtered runoff then percolates through the uncompacted soil base into the groundwater supply.

Porous concrete is placed using forms, then leveled with a screed. No finishing is required, and jointing is optional. *Take care not to overwork the surface.*

Porous concrete is applicable to many light-duty uses, including overflow parking areas, residential street parking lanes, parking pads in parking lots, sidewalks, golf cart and bike paths, and emergency access lanes. With proper maintenance, including regular vacuuming of the surface to prevent clogging by sediment, porous concrete can have a minimum service life of 20 years.

2.7.1 Factors affecting porosity

Water to cementitious materials ratio : The w/cm, water to cementitious materials ratio, (here the cementitious materials include pozzolans such as fly ash and silica fume in addition to the hydraulic cements–portland cement and ground slag) is an exceedingly important parameter of the quality of the HCC. It is the main control of the compressive strength, abrasion resistance, and permeability. The w/cm can be estimated by petrographic means, or the cement content can be determined by chemical analysis and compared with the cement content specified. The petrographer may be requested to estimate the w/cm whenever concrete does not meet the compressive strength specifications. Whether requested or not, an estimate of this ratio should be a regularly scheduled portion of any general examination of the HCC. This chapter is primarily focused on the examination of hand specimens or polished surfaces.

2.7.2 Chemical Determination

If the compressive strength of the concrete is low, the chloride ion permeability is high, the microstructure of the paste appears to be sugary, an aggregate with a known high water demand was used, or more quantitative data are required, a chemically determined cement content of the hardened concrete may be indicated. The cost of this analysis and the arrangements with the chemist or testing laboratory are usually the responsibility of the client. The methods used over the years for this chemical determination are discussed by Hime (1978) and in ASTM C 1084. Other methods are discussed by Clemeña (1972) and Pistilli (1976). If the amount of water used is known (rare in field concrete), the w/cm can be calculated from this determination.

The proper chemical determination of the cement content requires the use of a method appropriate for the type of aggregate present. A chemical determination of the cement content gives a result that is an average of the cement content of the specimen and provides no information on the extreme conditions that may exist in local zones in the specimen and whose extent and continuity may be critical to the strength and durability of the subject concrete. The selection of the particular portion of a specimen for analysis will affect the results. The chemical method cannot distinguish between cement that has been tied up in only partially hydrated rims and balls and cement that has dispersed and hydrated and thus contributes to the strength of the HCC. If the portion selected has a large proportion of knots of cement or cement rims on aggregates or both, the results will indicate sufficient cement content. If the portion selected is a light-colored portion containing excess air voids, less than a normal amount of unhydrated cement, and paste with a sugary texture, the resultswill indicate a low cement content. The petrographer must use good judgment in selecting the portion of the specimen for chemical analysis to ensure that it is as representative as possible. There may be no representative portion of the specimen that is of sufficient size for chemical analysis. In such cases, the petrographer might inform the client about the data already obtained and recommend procuring additional specimens.

The result of the cement analysis is reported (usually to the client) in kilograms per cubic meter (kg/m^3). If the reported amount of cement is significantly less than the amount of cement intended to have been used in the mixture, then the w/cm is high and either the volume of the concrete increased (usually because of excess water) or less than the prescribed amount of cement was used. Because the analysis is not performed on specimens of HCC suspected of having a normal or low w/cm, we have never had to report a case where the cement content indicated that a significant excess of cement was added or that a significant amount of water was omitted.

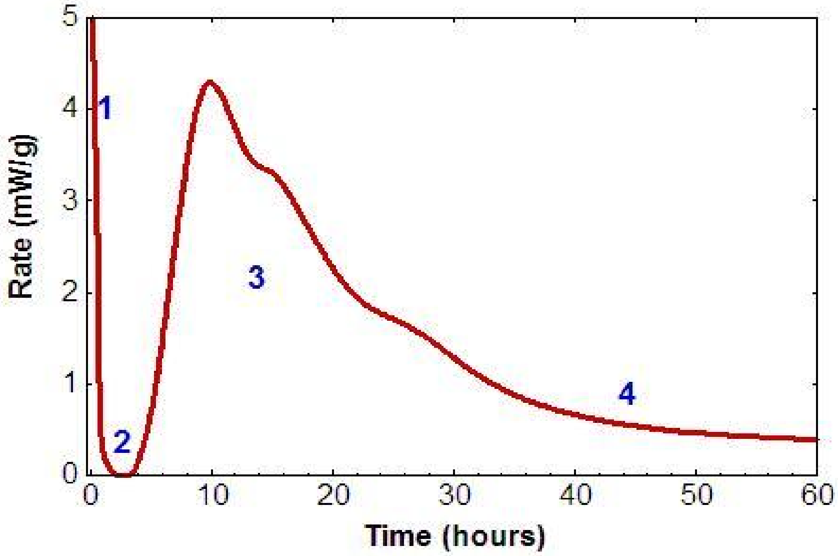
2.7.3 Degree of hydration :

The hydration of cement can be thought of as a two-step process. In the first step, called dissolution, the **Figure 2.1** cement dissolves, releasing ions into the mix water. The mix water is thus no longer pure H2O, but an aqueous solution containing a variety of ionic species, called the pore solution. The gypsum and the cement minerals C_3S and C3A are all highly soluble, meaning that they dissolve quickly. Therefore the concentrations of ionic species in the pore solution increase rapidly as soon as the cement and water are combined. Eventually the concentrations increase to the point that the pore solution is supersaturated, meaning that it is energetically favorable for some of the ions to combine into new solid Cases rather than remain dissolved. This second step of the hydration process is called precipitation. A key point, of course, is that these new precipitated solid Cases, called hydration products, are different from the starting cement minerals. Precipitation relieves the supersaturation of the pore solution and allows dissolution of the cement minerals to continue. Thus cement hydration is a continuous process by which the cement minerals are replaced by new hydration products, with the pore solution acting as a necessary transition zone between the two solid states. The reactions between portland cement and water have been studied for more than a hundred years, and the fact that hydration proceeds by a dissolution-precipitation process was first elaborated by the famous chemist Le Chatelier [1].

There are two reasons that the hydration products are different from the cement minerals. One reason is that there is a new reactant in the system: water. Not only does the water facilitate the hydration process by dissolving the cement minerals, but it also contributes ions, in the form of hydroxyl groups (OH-), to the hydration products. The second reason is the tendency for all processes to approach thermodynamic equilibrium. This dictates that the solid Cases that precipitate out of the pore solution are the ones that are the most stable under the current conditions. The stability of a Case is defined by a parameter called the free energy, which can be roughly defined as the amount of chemical and thermal energy contained in the Case. The lower the free energy, the more stable the Case. the cement minerals are formed at temperatures exceeding 1400?C, because they have the lowest free energy under those extreme conditions. At the much lower temperatures present during cement hydration, the cement minerals are actually quite unstable, meaning that there are many other solid Cases that will form preferentially in their place once they dissolve. In fact, the whole point behind the high-temperature cement manufacturing process is to create solid Cases that will readily dissolve in water, allowing new Cases to form. When one Case is converted into another Case with a lower free energy, there is usually a release of excess energy in the form of heat. Such a reaction is termed exothermic, and the exothermic heat associated with cement hydration has already been defined as the heat of hydration.

2.7.4 Schematic of the rate of hydration or heat evolution as a function of time

Shows a graph of the rate of cement hydration over time, with the hydration process divided into four somewhat arbitrary stages. Information about the rate of a reaction is called kinetics.. Here we will use the general behavior shown in Figure to discuss the various processes that occur during hydration.



2.1 Figure : Schematic of the rate of hydration or heat evolution as a function of time.

As noted above, some of the cement minerals and constituents are very soluble, and thus when cement and water are first combined there is a short period of fast reaction and heat output as the cement dissolves, lasting for less than one minute (Stage 1). Stage 1 is brief because of the rapid formation of an amorphous layer of hydration product around the cement particles, which separates them from the pore solution and prevents further rapid dissolution. This is followed by the induction period, during which almost no reaction occurs (Stage 2). The precise nature of the induction period, and in particular the reason for its end, is not fully known, or perhaps it should be stated that it is not fully agreed upon, as there are strongly held but differing opinions among cement chemists.

During Stage 3, the rapid reaction period, the rate of reaction increases rapidly, reaching a maximum at a time that is usually less than 24 hours after initial mixing, and then decreases rapidly again to less than half of its maximum value. This behavior is due almost entirely to the hydration of the C_3S, and the rate of hydration is controlled by the rate at which the hydration products nucleate and grow. Both the maximum reaction rate and the time at which it occurs depend strongly on the temperature and on the average particle size of the cement. This reaction period is sometimes divided into two stages (before and after the maximum rate) but as the rate-controlling mechanism is the same throughout (nucleation and growth) it is preferable to treat this as single stage.

At the end of Stage 3 about 30% of the initial cement has hydrated, and the paste has undergone both initial and final set. Stage 3 is characterized by a continuous and relatively rapid deposition of hydration products (primarily C-S-H gel and CH) into the capillary porosity, which is the space originally occupied by the mix water. This causes a large decrease in the total pore volume and a concurrent increase in strength. The microstructure of the paste at this point consists of unreacted cores of the cement particles surrounded by a continuous layer of hydration product, which has a very fine internal porosity filled with pore solution, and larger pores called capillary pores.

In order for further hydration to take place, the dissolved ions from the cement must diffuse outward and precipitate into the capillary pores, or water must diffuse inward to reach the unreacted cement cores.

2.7.5 Diffusion Process

These diffusion processes become slower and slower as the layer of hydration product around the cement particles becomes thicker and thicker. This final period (Stage 4) is called the diffusion-limited reaction period.

Figure 2-2 shows the microstructure of a cement paste at it hydrates, as simulated by a realistic digital image based model [ ]. The yellow Case is the main hydration product, C-S-H gel. At the end of Stage 3, the yellow rims if hydration product have become interconnected, causing final set and giving paste some minimal strength. By 28 days the image is dominated by C-S-H gel and the porosity has noticeably decreased. The final amount of porosity will depends strongly on the initial w/c of the paste.

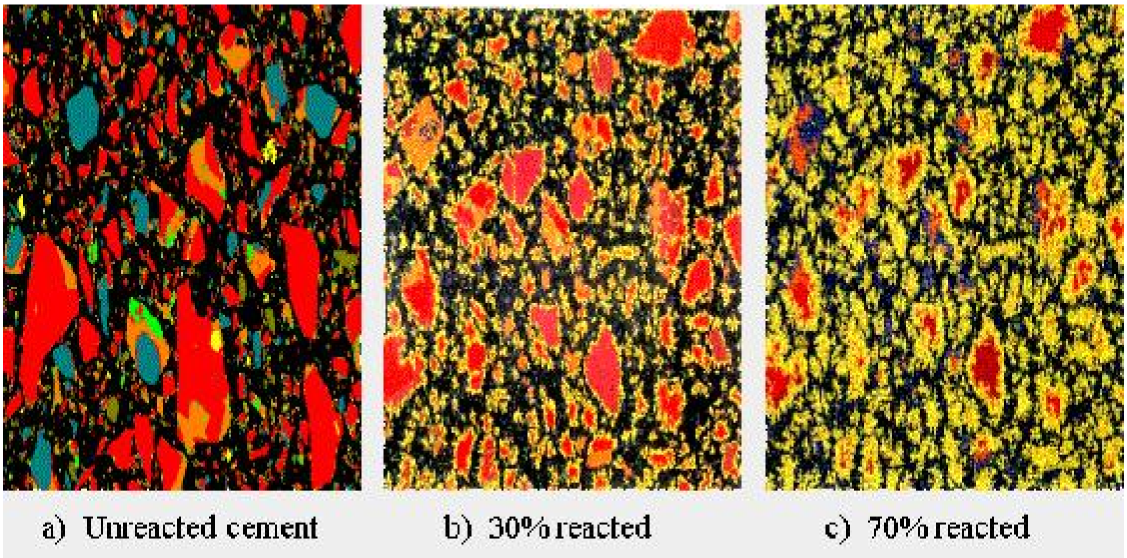

a) Unreacted cement b) 30% reacted c) 70% reacted

Figure 2.2 : Results of a realistic digital model of cement hydration. Cases are color coded: Black=water (pores), Red = C_3S, Blue = C2S, Yellow = C-S-H gel. a) Cement particles dispersed in water just after mixing. (Stage 1). b) 30% hydration, ~ 1 day (end of Stage 3). c) 70% hydration, ~ 28 days (Stage 4). (Images courtesy of NIST).

The overall progress of the hydration reactions is described by the degree of hydration, , which is simply the fraction of the cement that has reacted. Complete hydration of all the cement gives = 1. The degree of hydration can be measured in a few different ways, including x-ray measurements to determine how much of the minerals remain and loss on ignition measurements to determine how much bound water the paste contains. Another common method is to sum the amount of heat given off by the paste (as measured by thermal calorimetry) and divide this value by the total amount of heat given off for complete hydration. The latter value will depend on the mineral composition of the cement. Another parameter that can be used to monitor the progress of hydration is the compressive strength. This is not a precise measure, since the strength depends on many factors other than the progress of the chemical reactions, but it is very practical since the development of strength is the primary reason for using cement and concrete in the first place. Figure 2-3 shows the degree of hydration ( ), and the strength of a Type I OPC paste plotted as a function of time on the same graph. Note that the time is plotted on a log scale.

From Figure 2-3 it can be seen that the degree of hydration and the strength track together, particularly at later times. This is because the strength of cement paste depends primarily on the amount of capillary porosity, and the amount of capillary porosity decreases in proportion to the amount of hydration that has taken place. This decrease occurs because the C-S-H gel Case (including its internal gel pores) occupies significantly more volume than the cement minerals it forms from.

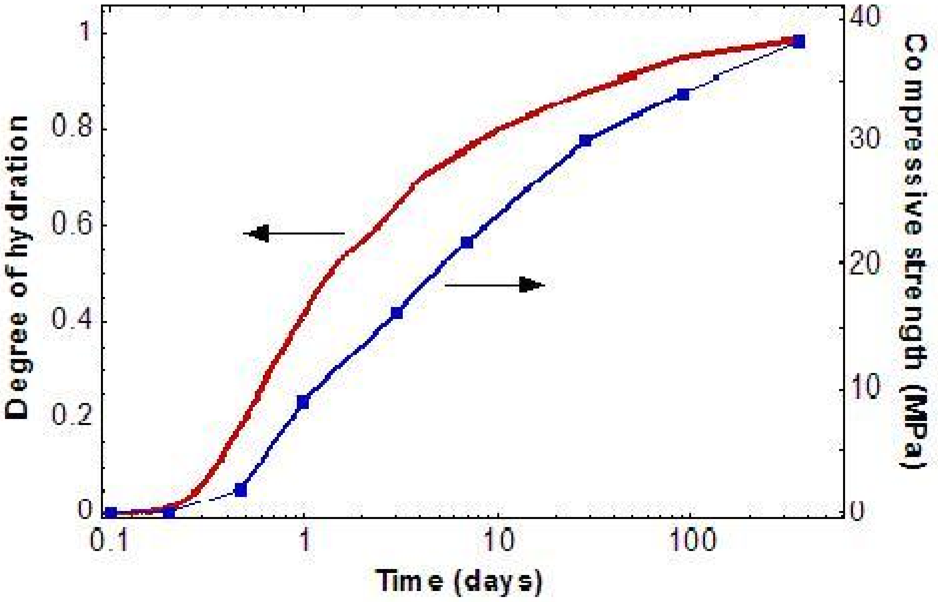


Figure 2-3: Typical development of the degree of hydration and compressive strength of a Type I portland cement over time.

In Figure 2-3 alpha has reached a value of 1 (complete hydration) after one year, but this will not always be the case, as many cement pastes will never reach full hydration. Depending on why hydration terminates, incomplete hydration may or may not be a bad thing. The final degree of hydration will depend on the w/c of the paste, the cement particle size, and the curing conditions. Hydration will continue at a slow rate during Stage 4 until one of the three following criteria is met:

1) All of the cement reacts. This is the situation shown in Figure 2-3. This indicates that the paste has a moderate or high w/c and was cured correctly. While it is the best possible outcome for the given mix design, it does not guarantee high quality concrete as the w/c may have been too high. If the cement contains some large particles, full hydration of these particles may not occur for years. However this is generally not the case with modern cements.

2) There is no more liquid water available for hydration. If the cement has a w/c less than about 0.4, there will not be enough original mix water to fully hydrate the cement. If additional water is supplied by moist curing or from rainfall, hydration may be able to continue. However, it is difficult to supply additional water to the interior of large concrete sections. If the cement is improperly cured so that it dries out, hydration will terminate prematurely regardless of the w/c. This is the worst-case scenario, as the strength will be lower (perhaps significantly) than the value anticipated from the mix design.

3) There is no more space available for new reaction product to form. When the capillary porosity is reduced to a certain minimal level, hydration will stop even if there is unreacted cement and a source of water. This is the best possible outcome,

and it is only possible if the w/c is less than about 0.4. Not only will the cement paste or concrete have a high strength, but it will also have a low permeability and thus be durable

2.7.6 Air content. :

Air-entrained concrete is typically specified in areas of the country where frost-related damage can occur. The measurement of air content in fresh concrete of normal density is typically performed using the pressure method (ASTM C 231). Another useful test is ASTM C 173. However, the pressure method is frequently preferred because it is relatively fast.

You should begin the test within 15 minutes after obtaining the composite sample. Start by filling the 0.25 ft^3 base of the air-content test device in three equal layers, and rod each layer 25 times. After rodding, strike the outside of the base with a mallet 12 to 15 times to close any air voids. After completing the three equal layers, strike off the bowl flush at the top to completely fill the 0.25 ft^3 volume. At this point, it can be weighed as part of the calculation to determine the fresh concrete unit weight.

Next, latch the top of the air-content test device over the base and fill the air gap between the top of the struck-off concrete and the underside of the top of air meter with water. The meter top is then pressurized with the built-in hand pump until zeroed out (or as calibrated). After a stabilization period, release the pressure in the top and read the air-void content on the dial on the top of the meter. Subtract the aggregate correction factor from the dial reading and report the final value.

2.8 Measurement of Air Content in Concrete

Michelle L. Wilson, Portland Cement Association

AASHTO T152

(ASTM C231)

AASHTO T 196

(ASTM C173)

AASHTO T 121

(ASTM C138)

AASHTO T 199

Several techniques are available for measuring the air content of fresh concrete. This article describes five techniques for use with fresh concrete and one technique for use with hardened concrete. The reader is referred to the appropriate AASHTO or ASTM standard for full details of each procedure. Failure to maintain and calibrate equipment and to properly follow test procedures are primary causes of problems in the measurement of air content. Samples should always be obtained in accordance with AASHTO T 141 (ASTM C172) Standard Method of Test for Sampling Freshly Mixed Concrete.

2.8.1 Pressure Method—AASHTO T 152 (ASTM C231)

AASHTO T 152, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method is based on Boyle's law, which states that the volume occupied by air is proportional to the applied pressure. Two types of meters designated A and B are covered by the standard. The Type A meter is rarely used. With the Type B meter shown in the photograph, a separate air chamber is connected through a valve to the test bowl that is filled with concrete. With the valve closed, the separate chamber is pressurized to a predetermined operating pressure. When the valve is opened, the air expands into the test chamber, and the pressure drops in proportion to the air contained within the concrete sample. The pressure gauge is read in units of air content. Sources of error in the pressure method include incomplete sample consolidation; over vibration; error in the pressure gauge which may result in incorrect application of pressure or in gauge malfunction; calibration tests; sampling methods; aggregate correction factor; and leaks in the needle valve, petcocks, or a poor fit when the mating surfaces are not clean.

The pressure meter should not be used for concrete made with lightweight aggregates. In these instances, the volumetric method should be used.

2.8.2 Volumetric Method—AASHTO T 196 (ASTM C173)

AASHTO T 196, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method relies on displacement of air with water in a vessel of pre-calibrated volume. To perform the test, the concrete is consolidated into the bowl, the apparatus filled with water, and a measured quantity of 70% isopropyl alcohol is added to dispel the foam generated during agitation. Next, the meter is inverted and agitated to free the concrete from the base and to displace air from the concrete into the water. The meter is then "rolled and rocked" until all the air has been dispelled from the concrete and the water level is stable. The air content of the concrete is read directly from the sight tube.

Major sources of error in the volumetric air test are failure to dispel all the air from the concrete during the agitation process, and difficulty in reading the liquid level in the sight tube. Other sources of error include possible variations in percentage of alcohol, use of alcohols other than isopropyl, and failure to allow sufficient time for stability of the reading.

2.8.3 Gravimetric Method—AASHTO T 121 (ASTM C138)

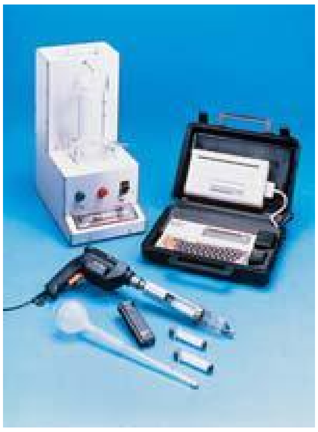
AASHTO T 121, Standard Method of Test for Density (Unit Weight), Yield, and Air Content [Gravimetric] of Concrete determines air content of fresh concrete by comparing measured density or batch volume to calculated density or volume. The density (unit weight) is determined by weighing a known volume of fresh concrete. The air content is computed using two independent equations given in AASHTO T 121. A significant discrepancy in the results from the two equations is an alert to check test equipment, procedures, sampling, mix ingredients, and proportions.

The test is sensitive to consolidation and strike-off of the concrete in the container; accurate weighing; and the need for precise batch weights, moisture contents, and densities of all constituent materials.

2.8.4 Chace Air Indicator—AASHTO T 199

AASHTO T 199, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Chace Indicator is identical in concept to the volumetric air meter, but the air collected in this hand-held device has been liberated from a small fraction of mortar. The sample size is so small that this is a semi-quantitative test at best, and should not be a substitute for the more accurate pressure, volumetric, and gravimetric methods. It should not be used for determining the compliance of air content with the specifications.

Air Void Analyzer



The air void analyzer (AVA) determines the volume and size distributions of air voids; thus an estimation of the spacing factor, specific surface, and total amount of entrained air can be made. Air bubbles from a sample of fresh concrete rise through a viscous liquid, enter a column of water above it, then rise through the water and collect under a submerged buoyancy recorder. The viscous liquid retains the original bubble sizes. Large bubbles rise faster than small ones. The change in buoyancy is recorded as a function of time and can be related to the number of bubbles of different sizes

2.8.5 Air-Void System—ASTM C457

ASTM C457, Standard Test Method for Microscopical Determination of Parameters of the Air- Void System in Hardened Concrete describes procedures for microscopical determination of the air content of hardened concrete and of the specific surface, void frequency, spacing factor, and paste-air ratio of the air-void system in the hardened concrete. Differences between the air content measured on fresh and hardened concrete from the same batch are generally not more than ± 2 percentage points.

2.9 Consolidation.

Good concrete consolidation is essential. Lack of consolidation can cause voids, rock pockets, honeycombing, and poor bonding with the rebar. In extreme cases, improper consolidation can affect the structural integrity of the walls. On the other hand, excessive vibration can create bulged walls and blowouts.

How much vibration does an ICF wall need, and what is the best way to do it? Good consolidation is a combination of different factors, and vibration is only one of them. Suitable mix design and correct placement technique are critical, but are not discussed in this article.

Vibration and ICFs is an area that generates significant controversy. ICF-related discussion forums reveal a broad range of opinions and method. In finding an effective solution for you, the principles below should provide general guidelines.

Modern Forms Are Strong
Much of the confusion over how to vibrate ICFs comes from outdated information. Today's ICFs can withstand internal vibration, and nearly all manufacturers strongly encourage it. But that hasn't always been the case. As recently as the late 1990's, some ICF designs did not have the strength to handle adequate vibration.

ontractors were advised to use orbital sanders, reciprocating saws with the blade removed, or even to "bang on the blocks with a short length of 2x4."Unfortunately, these methods do not provide sufficient consolidation. Even more regrettably, these sub-par methods are still being used by some contractors.

Review an up-to-date installation manual or talk to the technical director at your preferred ICF company to get their latest recommendations about consolidation techniques. If these sources reveal that the form will not withstand internal vibration, consider switching to a more modern ICF design. Jobs with inadequate consolidation not only damage your reputation, but that of the entire industry.

The Portland Cement Association (PCA) conducted an in-depth study of concrete consolidation and ICFs. They tested flat panels with 4- and 6-inch cores, as well as a screen grid and waffle grid ICFs. Panels with corners and lintels were also tested. Test sections were filled with low- (3"), medium- (6") and high-slump (8"-10") concrete and vibrated with wood blocks, saws, sanders, and internal vibrators. They also filled test panels with a self-consolidating concrete (SCC).

In every case, walls filled with low-slump mixes had poor consolidation, regardless of the technique used. "External mechanical vibration using a hammer, reciprocating saw, or orbital sander did not significantly improve the consolidation of concrete in ICF walls…"

On the medium slump panels, external vibration scored slightly better, but not nearly as well as those that used an internal vibrator. High-slump concrete and SCC achieved adequate consolidation with minimal vibration.

Alternative Consolidation Methods

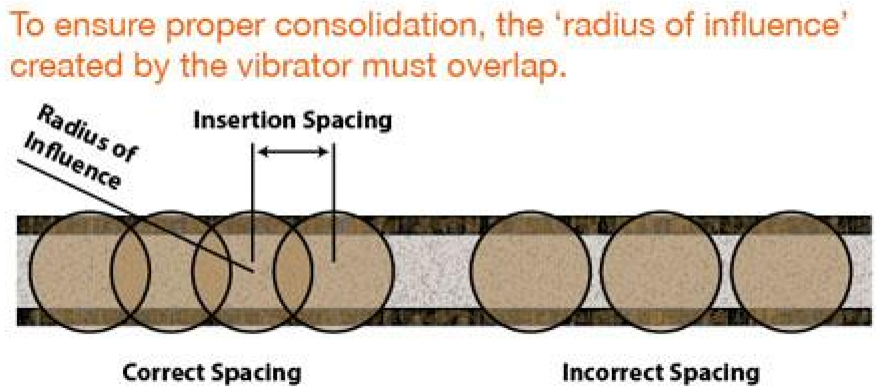
Internal vibrators do have drawbacks. For instance, they can get caught in the rebar causing damage to the wall or vibrator. This is likely to happen in critical areas, since rebar is most congested there. Since the PCA study in 2003, a number of innovative concrete consolidation methods have been developed to avoid these problems, including external vibrators and rebar shakers. Few formal studies have been done comparing their effectiveness, but here's what we know:

Rebar Shakers: The Oztec Rebar shaker is perhaps the best-known alternative vibration technique. It's based on their regular electric vibrator, but instead of the regular head that's inserted into the concrete, it uses a proprietary device that is slipped over the top of the rebar, and uses the rebar itself to transmit vibrations into the concrete. It comes in two sizes, the smaller can handle up to #7 bar. Oztec claims the device offers "tremendous savings in man-hours and dramatically reduces clean-up."

Some contractors who have used the device claim that it doesn't work as well in ICFs, since horizontal and vertical rebar often isn't tied together, and that it actually decreases strength since it pushes aggregate away from the bar, leaving it embedded only in cement paste.

To refute these myths, Oztec sponsored testing to compare a rebar shaker and a pencil vibrator. The test was conducted at the University of Tennessee by three professional engineers. In each test, the bond between the grout and the reinforcing bar was verified by performing pullout tests on the reinforcing bar. The wall was then destructed to ascertain the completeness of the grout consolidation.

The report concludes, "The reinforcing bar embedded in grout consolidated with the Oztec Rebar Shaker met all code development length requirements and was able to develop the full rupture strength of the #4 bars. No voids were observed in the grout consolidated with the Oztec/Rhodes Rebar Shaker and good complete bond was observed with the reinforcing bar. We recommend that the Oztec Rebar Shaker be fully recognized as an acceptable alternative to the conventional pencil vibrator."



A copy of the complete report can be viewed in the online version of this article. Because the zone of influence is limited with rebar shakers, Oztec recommends using a regular pencil head vibrator for jobs with rebar spacing of more than 12" on center.

2.9.1 External Board Vibrators:

These first appeared on the scene about three years ago, made by Brecon and marketed by Houston Vibrator. They work to vibrate the concrete from the outside of the formwork, and consist of a flat aluminum panel connected to a 115-volt electric motor. The size of the panel can be adjusted to fit the operator's needs, but usually measures 12"x36".Like the internal vibrators, the operator starts at the bottom of the wall and works his way upward to the top of the wall.

Advantages include less mess, practically no clean-up, and no loss of time dealing with rebar issues. Disadvantages include the fact that the entire height of the wall needs to be accessible, and the device can become heavy and cumbersome—although no more than internal vibrators can be.

2.9.2 External Rotary Vibrators: These small, handheld vibrators are usually powered by cordless drills. Two of the most popular brands are the Arkie Wall Banger and Lite-Form Technologies' Wallbrator. Both are about six inches in diameter and weigh less than three pounds. They can access hard-to-reach areas better than most other options. Either product works better than sanders, saws, and 2x4s, but questions remain about whether they actually improve rebar encapsulation. The author is unaware of any formal testing revealing their effectiveness.

An ICF structure is only as strong as the concrete core within the walls. As durability and energy efficiency become more important than ever, so does proper consolidation. Ian Geisler, a Texas-based ICF builder says, "We all need to learn how to properly consolidate concrete, as one bad project affects all of us. Also, more and more commercial projects are coming on line. With more commercial work comes more specs for steel and they bring out more inspectors. There's no excuse not to do the job right."

2.10 Admixture of Concrete

Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; and to overcome certain emergencies during concrete operations.

Successful use of admixtures depends on the use of appropriate methods of batching and concreting. Most admixtures are supplied in ready-to-use liquid form and are added to the concrete at the plant or at the jobsite. Certain admixtures, such as pigments, expansive agents, and pumping aids are used only in extremely small amounts and are usually batched by hand from premeasured containers.

2.10.1 Effectiveness of Admixture

The effectiveness of an admixture depends on several factors including: type and amount of cement, water content, mixing time, slump, and temperatures of the concrete and air. Sometimes, effects similar to those achieved through the addition of admixtures can be achieved by altering the concrete mixture-reducing the water-cement ratio, adding additional cement, using a different type of cement, or changing the aggregate and aggregate gradation.

2.11 Five Functions

Admixtures are classed according to function. There are five distinct classes of chemical admixtures: air-entraining, water-reducing, retarding, accelerating, and plasticizers (superplasticizers). All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring. Air-entraining admixtures, which are used to purposely place microscopic air bubbles into the concrete, are discussed more fully in Air-Entrained Concrete.

2.11.1 Water-reducing admixtures

Usually reduce the required water content for a concrete mixture by about 5 to 10 percent. Consequently, concrete containing a water-reducing admixture needs less water to reach a required slump than untreated concrete. The treated concrete can have a lower water-cement ratio. This usually indicates that a higher strength concrete can be produced without increasing the amount of cement. Recent advancements in admixture technology have led to the development of mid-range water reducers. These admixtures reduce water content by at least 8 percent and tend to be more stable over a wider range of temperatures. Mid-range water reducers provide more consistent setting times than standard water reducers.

2.11.2 Retarding admixtures

Which slow the setting rate of concrete, are used to counteract the accelerating effect of hot weather on concrete setting. High temperatures often cause an increased rate of hardening which makes placing and finishing difficult. Retarders keep concrete workable during placement and delay the initial set of concrete. Most retarders also function as water reducers and may entrain some air in concrete.

2.11.3 Accelerating admixtures

Increase the rate of early strength development, reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather.

2.11.4 Superplasticizers,

It isknown as plasticizers or high-range water reducers (HRWR), reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction. The effect of superplasticizers lasts only 30 to 60 minutes, depending on the brand and dosage rate, and is followed by a rapid loss in workability. As a result of the slump loss, superplasticizers are usually added to concrete at the jobsite.

2.11.5 Corrosion-inhibiting admixtures

It is fall into the specialty admixture category and are used to slow corrosion of reinforcing steel in concrete. Corrosion inhibitors can be used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride. Other specialty admixtures include shrinkage-reducing admixtures and alkali-silica reactivity inhibitors. The shrinkage reducers are used to control drying shrinkage and minimize cracking, while ASR inhibitors control durability problems associated with alkali-silica reactivity.

2.12 Effect on permeability

The permeability and porosity of concrete containing calcium chloride in relation to a plain concrete depends on two conflicting variables:

1.The degree of hydration of the concrete, which in the case of the calcium chloride-containing concrete will initially be considerably increased, and the larger volume of hydration products will lead to a reduced permeability.

2. The adverse effect that calcium chloride has on the capillary porosity distribution. At later ages (after perhaps 1 year) the degree of hydration in both calcium chloride-containing concrete and a plain concrete will be similar and, under these circumstances, the concrete will be more porous and allow easier access to aggressive gases and liquids

2.13 Effect on shrinkage

The drying shrinkage of concrete containing calcium chloride is increased in comparison to plain concrete, even though the amount of moisture lost is less (Rixom and Mailvaganam, 1999). This is illustrated in Fig. 2.3 and it is thought that the reduced moisture loss will be due to the more advanced state of hydration in the specimens containing calcium chloride. The increased shrinkage must, therefore, be a characteristic of the type of cement hydration products formed. Under saturated conditions, such as total water immersion, the amount of expansion of the concrete is reduced when calcium chloride is present. There are only limited data available on the effect of other accelerating admixtures, although one comparative study by Bruere et. al (1971) suggests that calcium formate and triethanolamine also increase the drying shrinkage of concrete into which they are incorporated.

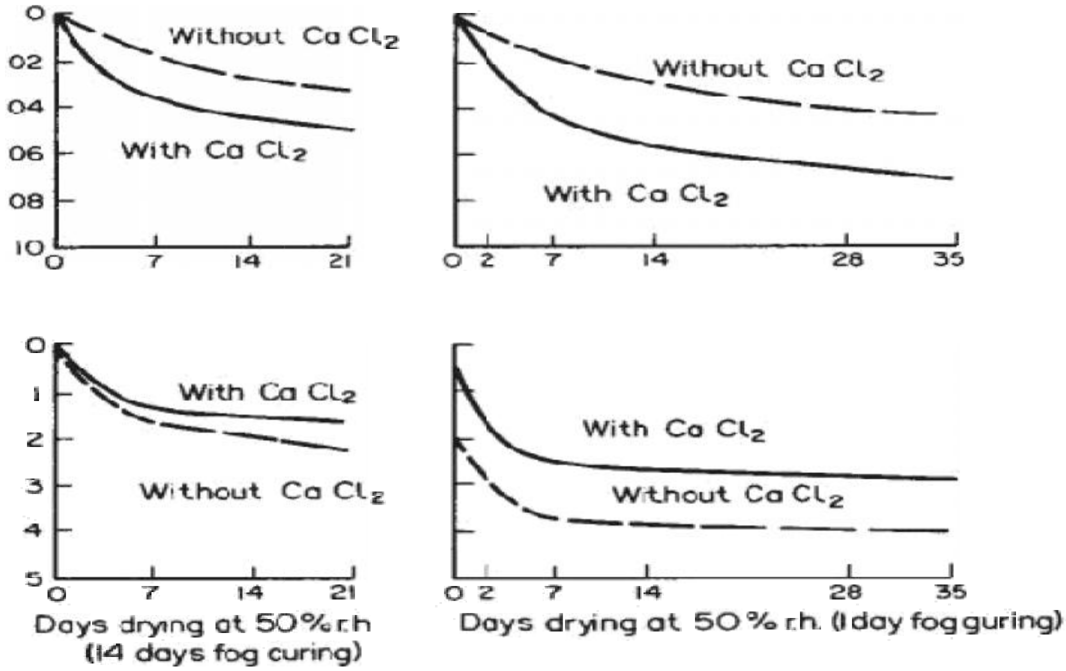


Figure 2.4: $CaCl_2$ increases drying shrinkage of concrete, although the moisture content is decreased. (Source: Rixom and Mailvaganam, 1999)

2.14 Effect on workability

It is generally observed that addition of $CaC1_2$ increases slightly the workability and reduces the water required to produce a given slump of concrete. In combination with an air-entraining agent, $CaCl_2$ may sometimes improve further the workability. A small increase in air content and average size of air voids may also result (Ramachandran, 1995).

Chapter-3

METHODOLOGY

3.1. Materials collection and properties

The materials used for this experiment, all are locally available and chemical and physical properties are describe below.

3.1.1. Cement

This research was done using two type of cement. Ordinary Portland cement (OPC) and Portland composite Cement (PCC). For the chemical composition of OPC cement, this is CEM I type where as PCC cement is CEM II/B.PCC cement was commercially available. So it was easy to get where as OPC cement was not available in market. So it required to contact with *Holcim Cement Bangladesh Ltd.* the manufacturer of OPC cement to get. Chemical and Physical properties of OPC and PCC cement are given below was collected from the manufactured company.

Table 3.1 :- Chemical composition for CEM I (OPC Cement)

Chemical Composition	BDS En-197-1;2003, CEM I 52.5 N Spec.	Control Limit (%)	Test Result Typical (%)
Silicon Dioxide(SiO_2)	-	20.10~22.00	20.62
Aluminium Oxide ($Al2O_3$)	-	4.50~6.30	5.66
Ferric Oxide (Fe_2O_3)	-	3.15~3.60	3.19
Calcium Oxide (CaO)	-	61.18~64	63.90
Magnesium Oxide (MgO)	-	1.25~2.5	1.76
Sulfur Trioxide (SO_3)	≤4.00	Max 3.0	2.14
Loss On Ignition (LOI)	≤5.00	Max 2.00	1.09
Chloride Content (Cl)	≤.10	0.01~0,02	0.0113
Insoluble Residue (IR)	≤5.00	Max 2.00	0.51
Free Lime (F/Cao)		≤1.50	1.12

Table 3.2 :- Physical properties for CEM I (PCC Cement)

Physical Properties	BDS En-197-1;2003, CEM I 52.5 N Spec.	Control Limit (%)	Test Result Typical (%)
Sp. Gr. (M^2/Kg)	Not Specified	320~350	340
Fineness , Blaine Test	≤10	Max 1.0	0.50
Soundness (mm)			
Compressive Strength (MPa)			
2-Days Strength	≥20	22~25	24.48
7-Days Strength	-	38~42	40.05
28-Days strength	≥52.5	Min 53	55.20
Time of Setting (Minutes)			
Initial Setting	≥45	140~160	140
Final Setting	-	240~260	250

Table 3.3:- Chemical composition for CEM II/B

Chemical Composition	BDS EN-197-1,CEM II/B-M(V-S-L)42.5N	Control Limit(%)	Test Result Typical%
Silicon Dioxide(SiO_2)	-	29.00~33.00	30.63
Aluminium Oxide($Al2O_3$)	-	8.00~11.00	10.84
Ferric Oxide (Fe_2O_3)	-	3.30~3.90	3.59
Calcium Oxide (CaO)	-	47.0~50.00	49.30
Magnesium Oxide (MgO)		1.5~2.50	1.58
Sulfur Trioxide (SO_3)	≤3.5%	1.80~2.40	2.01
Loss On Ignition (LOI)	-	1.20~2.50	1.90
Chloride Content (Cl)	≤0.10%	0.01~0.04	0.0149
Free Lime (F/Cao)		≤1.20	0.90

Table 3.4 :- Physical properties for CEM II/B

Physical Properties	BDS En-197-1;2003, CEM II 52.5 N Spec.	Control Limit (%)	Test Result Typical (%)
Sp. Gr. (M^2/Kg)	Not Specified	370~400	393
Fineness , Blaine Test	≤10	Max 1.0	0.50
Soundness (mm)			
Compressive Strength (MPa)			
2-Days Strength	≥10	16~20	18.02
7-Days Strength	-	28~32	31.65
28-Days strength	≥42.5 & ≤62.5	Min 45	47.85
Time of Setting (Minutes)			
Initial Setting	≥60	180~210	190
Final Setting	-	270~300	290

3.1.2.Sand

The problem was faced to collect sand and cement. Sand was also available but as for research purpose the quantity was very small so it was not way to get as commercially. So amount of sand was collected from construction side with the help of social relationship.

Sand was used that can pass through #4 sieve. The properties of sand is below:
For this research we use sand that belongs the FM=2.60.
Bulk Specific Gravity (Oven Dry Basis) S_d= 2.35
Bulk Specific Gravity (SSD Basis) S_s= 2.38
Apparent Specific Gravity S_a=2.42
Absorption Capacity =1.2%

3.1.3 Water

Water was used for this experiment is tap water. Temperature was maintained around 25^0C.

3.2. Physical properties Determination of Materials:

Some Physical properties of sand were determined like Specific Gravity, Absorption Capacity and FM. The test was done according to code ASTM C128 and C136 respectively.

3.2.1. Sieve Analysis of Fine Aggregate.

The term sieve analysis is given to the simple operation of diving a sample of aggregate into fraction each consisting of particles between specific limits.The analysis is conducted to determine the grading of materials proposed for use as aggregates or being used as aggregates.

The term fineness modulas (F.M) is a ready index of fineness of the material.It is an empirical factor obtained by adding the cumulative percentages of aggregates retained on each of the standard sieves and dividing this sum arbitrarily by 100.

No. 100, No. 50, No. 30, No. 16, No. 8, No. 4, 3/8 in, ¾ in, 1.5 in are the ASTM standard sieves.

This test method conforms to the ASTM standard requirements of specification C136.

Apparatus:

Balance(sensitive to within 0.1% of the weight of the sample), Sieve(ASTM Standard),Mechanical sieve shaker.

Sampling:

Thoroughly mix the sample and reduce it to an amount, so that the sample for test shall be approximately of the weight desired when dry.

Fine Aggregate-

The test sample of fine aggregate (F.A) shall weight, after drying, approximately the following amount:

Aggregate with at least 85% passing a No.4 sieve and more than 5% retained on a No. 8 sieve.	500g
Aggregate units at least 95% passing No.8 sieve	100g

Procedure For FA:

1. Dry the sample to constant weight at a temperature of 110+5C
2. Nest the sieve in order of decreasing size of opening from top to bottom and place the sample on the top sieve.
3. Agitate the sieve by hand and by mechanical apparatus for a sufficient period, say 15 minutes.
4. Limit the quantity of material on a given sieve so that all particles have the opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75 mm (No. 4), the weight retained on any sieve at the completion shall not exceed 6 kg/m2 (4 g/in2) of sieving surface. For sieves with openings 4.75 mm (No.4) and larger, the weight in kg/m2 of sieving surface shall not exceed the product of 2.5*(sieve opening in mm). In no case shall the weight be so great as to cause permanent deformation of the sieve cloth.
5. Continue sieving for a sufficient period and in such manner that, after completion, not more than 1 weight % of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving.
6. Determine the weight of each size increment by weighting on a scale or balance to the nearest 0.1% of the total original dry sample weight. The total weight of the material after sieving should check closely with original weight of sample placed on the sieves. If the amount differ by more than 0.3% based on the original dry sample weight,the results should not be used for acceptance purpose.

Calculation:

1. Calculate percentages passing, total percentage retainedor percentages in various size fractions to the nearest 0.1% on the basis of the total weight of the initial dry sample.

Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100:150-um (no. 100), 300-um (no.50), 600-um (no .30), 1.18-mm (no.16),2.36-mm(no.8), 4.75-mm (no. 4), 9.5-mm (3/8-in),37.5-mm(1.5 in),and larger, increasing in the ratio of 2 to 1.

3.2.2 Specific Gravity and Absorption Capacity of Fine Aggregate.

Aggregate generally contain pore, both permeable and impermeable, for which specific gravity has to be carefully defined. With this specific gravity of each constituent known, its weight can be converted into solid volume and hence a theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements. This test method covers the determination of bulk apparent specific gravity,23/23◦C (73.4/73.4◦F) and absorption of fine aggregate.

Bulk specific gravity is defined as the ratio of the weight of the aggregate (oven-dry or saturated surface dry) to the weight of water occupying a volume equal to that of the solid including the permeable pores. This is used for 1.calculation of the volume occupied by the aggregate in various mixtures containing aggregate on an absolute volume basis 2.the computation of voids in aggregate, and 3.the determination of moisture in aggregate.

Apparent specific gravity is the ratio of the weight of the aggregate dried in oven at 100 to 110◦C (212 to 230◦F) for 24 hrs.to the weight of water occupying a volume equal to that of the solid excluding the permeable pores.This pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles that is accessible to water.

Absorption values are used to calculate the change in the weight of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition. For an aggregate that has been in contact with water and that has been in contact with water and that has free moisture on the particle surfaces, the percentages of free moisture can be determined by deducing the absorption from the total moisture content.

This test method conforms to the ASTM standard requirements of specification C128.

Apparatus:

a) Balance-Sensitive to 0.1g or less.
b) Pycnometer-A flask or other suitable container of 1000 ml capacity. The volume of the container filled to mark shall be at least 50% greater than the space required to accommodate test sample of fine aggregate.
c) Mold-A metal mold in the form of a frustum of a cone with dimensions as follows:
   40±3 mm inside diameter at the top
   90±3 mm inside diameter at the bottom
   75±3 mm in height
   0.8 mm minimum thickness of metal

d) Tamper- A metal tamper weighting 350±15 g and having a flat circular tamping face 25±3 mm in diameter.

Preparation of Test Specimen:

a) Obtain approximately 1 kg sample of fine aggregate.

b) Dry it in a suitable pan or vessel to constant weight at a temperature of 110±5◦C(230±9◦F). Allow it to cool to comfortable handling temperature, cover with water, either by immersion or by the addition of at least 6% moisture to the fine aggregate, and permit to stand for 24±4 hr.

c) Cone test for surface moisture-Place a portion of the partially dried fine aggregate loosely in the mold by filing it to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand holding the mold. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm (o.2 in) above the top surface of the fine aggregate. Permit the tamper to fall freely under gravitational attraction on each drop and distribute the drops over the surface. remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the mold shape. Continue drying with constant stirring and test at frequent intervals until the cone of the sand slumps upon the removal of mold. When the fine aggregate slumps slightly it indicates that it has reached a surface-dry condition.

If the first trial of the surface moisture test indicates that moisture is not present on the surface , it has been dried past the saturated surface-dry condition. In this case thoroughly mix a few millilitres of water with the fine aggregate and permit the specimen to stand in a covered container for 30 minutes. Then resume the process of drying and testing at frequent interval for the onset of the surface-dry condition.

Procedure:

a) Partially fill the pycnometer with water. Immediately introduce into the pycnometer 500±10 gm of saturated surface-dry fine aggregate prepared and fill with additional water to approximately 90% of capacity. Roll, invert and agitate the pycnometer to eliminate all air bubbles. Adjust its temperature to 23±1.7◦C(73.4±3◦F), if necessary by immersion in circulating water, and bring the water level in the pycnometer to its calibrated capacity. Determine the total weight of the pycnometer, specimen, and water.

b)Remove the fine aggregate from the pycnometer, dry to constant weight at a temperature of 110±5◦C(230±9◦F), cool in air at room temperature for 1±1/2 hr, and weigh.

c)Determine the weight of the pycnometer filled to its calibration capacity with water at 23±1.7◦C(73.4±3◦F)

For determination of the Sp. Gr., We used the Equation below:

Bulk Sp. Gr. (OD Basis) $S_d = A/(B + S - C)$ ……………………(1)

Bulk Sp. Gr. (SSD Basis) $S_S = S/(B + S - C)$ ……………………(2)

Apparent Sp. Gr. $S_a = A/(B + A - C)$ …………………………(3)

Where, A=Weight of Oven dry Specimen in air, (gm)

B=Weight of pycnometer filled with, (gm)

S=Weight of the saturated surface-dry specimen, (gm) and

d C=Weight of pycnometer with specimen and water to calibration mark,(gm)

For Determination of Absorption Capacity of sand We used the equation below:

Absorption % = $(S - A)/A \text{ x}100$ ………………………… (4)

Or

Absorption % = $(Sa - Ss)/(Sa(Ss - 1)) \text{ x}100$………………(5)

Specific Gravity results to the nearest 0.01 and to the nearest 0.1%

For Determination of FM (Fineness Modulus) we used equations below:

FM=$(\text{Sum of the Cumulative \% of all Standard sieve })/(\text{weight of the total sample retained})$

3.3. Material mix proportion and mortar Sample

Materials were mixed in standard proportion according to Code ASTM C109.

W/C (Water: Cement) Ratio was 0.485. And Cement: Sand = 1:2.75.Materials were mixed using electrical mixing machine.2-in. or [50-mm] cube specimen was used for this experiment. Total volume of this specimen is 8 in^3. Cement mortar specimen of both OPC and PCC cement was casted for compressive strength and porosity test. ASTM C109 was followed for the preparation sample for compressive strength test.

3.4. Compressive strength test

Compressive strength test of cement mortar of OPC and PCC was done for different days curing. Specimens were kept in mold for 24 hours and demolded specimens were kept under lime water for curing. Cement mortar sample were crushed at 3, 14, 28, 42 and 56 days after demolding. Mortar samples were crushed on OD and SSD condition.

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structure applications concrete is employed primarily to resist compressive stresses. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the harden cement paste. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding and fabrication and the age, temperature, and moisture conditions during curing.

The results of this test method may be used as a basis for quality control of concrete proportioning, mixing and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures and similar uses.

The test method conforms to the ASTM standard requirements of specification C39 for cylinder and BS1881 for cube.

Apparatus:

Testing Machine: The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading as required.

a) Design-The machine must be power operated and must apply the load continuously rather than intermittently and without shock.

b) Accuracy-The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0% of the indicated load.

1.The testing machine shall be equipped with two steel bearing blocks with hardened faces, one of which is a spherical seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3% greater than the diameter of the specimen to be tested. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than ½ in (13 mm), concentric circles not more than 1/32 in (0.8 mm)deep and not more than 3/64 in (1.2 mm) wide shall be inscribe to facilitate proper centering.

2. Bottom bearing blocks shall conform to the following requirements:

The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions. The top and bottom surfaces tothe shall be parallel to each other. The block may be fastened to the platen of the testing machine. Its least horizontal dimension shall be at least 3% greater than the diameter of the specimen to be tested.

3.5. Preparation Of Cube specimens

Cube Moulds - 'The mould shall be ot metal, preferably steel or cast iron, and stout enough to prevent distortion. It shall be constructed in such a manner as to facilitate the removal of the moulded specimen without damage, and shall be so .machined that, when it is assembled ready for use, the dimensions and internal faces shall be accurate within the following limits: 'The height of the mould and the distance between opposite faces shall be the specified size + 0·2 mm. The angle between adjacent 6 IS: 516 - 1959 internal faces and between internal faces and top and bottom planes of the mould shall be 90° +0-5°. The interior faces of the mould shall be plane surfaces with

a permissible variation of 0·03 mm. Each mould shall he provided with a metal base plate having a plane surface. The base plate shall be of such dimensions as to support the mould during the filling without leakage and it shall be preferably attached to the mould by springs or screws, The parts of the mould when assembled shall be positively and rigidly held together. and suitable methods of ensuring this, both during the filling and on subsequent handling of the filled mould, shall be provided.
1 In assembling the mould for use, the joints between the sections of mould shall be thinly coated with mould oil and a similar coating of mould oil shall be applied between the contact surfaces of the bottom of the mould and the base plate in order to ensure that no water escapes during the filling. The interior surfaces of the assembled mould shall be thinly coated with mould oil to prevent adhesion of the concrete

The proportion and material for making these test specimens are from the same concrete used in the field.

3.6. Equipments and Machine

Specimen Molds, for the 2-in. or [50-mm] cube specimens shall be tight fitting. The molds shall have not more than three cube compartments and shall be separable into not more than two parts. The parts of the molds when assembled shall be positively held together. The molds shall be made of hard metal not attacked by the cement mortar. For new molds the Rockwell hardness number of the metal shall be not less than 55 HRB. The sides of the molds shall be sufficiently rigid to prevent spreading or warping. The interior faces of the molds shall be plane surfaces and shall conform to the tolerances Table 3.5.

Table 3.5 Permissible Variations of Specimen Molds

	2-in. Cube Molds		[50-mm] Cube Molds	
Parameter	New	In Use	New	In Use
Planeness of sides	<0.001 in.	<0.002 in.	[<0.025 mm]	[<0.05 mm]
Distance between opposite sides	2 in. ± 0.005	2 in. ± 0.02	[50 mm ± 0.13 mm]	[50 mm ± 0.50 mm]
Height of each compartment	2 in. + 0.01 in.	2 in. + 0.01 in.	[50 mm + 0.25 mm	[50 mm + 0.25 mm
	to − 0.005 in.	to − 0.015 in.	to − 0.13 mm]	to − 0.38 mm]
Angle between adjacent faces[A]	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°	90 ± 0.5°

(A) Measured at points slightly removed from the intersection. Measured separately for each compartment between all the interior faces and the adjacent face and between interior faces and top and bottom planes of the mold.

Cube molds shall be checked for conformance to the design and dimensional requirements of this test method at least every $2^1/_2$ years.

Mixer, Bowl and Paddle, an electrically driven mechanical mixer of the type equipped with paddle and mixing bowl, as specified in Practice **C305**.

Flow Table and Flow Mold, conforming to the requirements of Specification **C230/C230M**.

Tamper, a nonabsorptive, nonabrasive, nonbrittle material such as a rubber compound having a Shore A durometer hardness of 80 ± 10 or seasoned oak wood rendered nonabsorptive by immersion for 15 min in paraffin at approximately 392 °F or [200 °C], shall have a cross section of about $^1/_2$ by 1 in. or [13 by 25 mm] and a convenient length of about 5 to 6 in. or [120 to 150 mm]. The tamping face shall be flat and at right angles to the length of the tamper.

Tampers shall be checked for conformance to the design and dimensional requirements of this test method at least every $2^1/_2$ years.

Trowel, having a steel blade 4 to 6 in. [100 to 150 mm] in length, with straight edges.

Moist Cabinet or Room, conforming to the requirements of Specification **C511**.

Testing Machine, either the hydraulic or the screw type, with sufficient opening between the upper bearing surface and the lower bearing surface of the machine to permit the use of verifying apparatus. The load applied to the test specimen shall be indicated with an accuracy of ±1.0 %. If the load applied by the compression machine is registered on a dial, the dial shall be provided with a graduated scale that can be read to at least the nearest 0.1 % of the full scale load (**Note 2**). The dial shall be readable within 1 % of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment that is easily accessible from the outside of the dial case, and with a suitable device that at all times until reset, will indicate to within 1 % accuracy the maximum load applied to the specimen.

If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 % of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 % for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 % system accuracy the maximum load applied to the specimen.

Compression machines shall be verified in accordance with Practices **E4** at least annually to determine if indicated loads, with and without the maximum load indicator (when so equipped), are accurate to ±1.0 %.

NOTE 2: As close as can be read is considered $^1/_{50}$ in. or [0.5 mm] along the arc described by the end of the pointer. Also, one half of the scale interval is about as close as can reasonably be read when the spacing on the load indicating mechanism is between $^1/_{25}$ in. or [1 mm] and $^1/_{16}$ in. or [1.6 mm]. When the spacing is between $^1/_{16}$ in. or [1.6 mm] and $^1/_8$ in. or [3.2 mm], one third of the scale interval can be read with reasonable certainty. When the spacing is $^1/_8$ in. or [3.2 mm] or more, one fourth of the scale interval can be read with reasonable certainty.

The upper bearing assembly shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 % of the radius of the sphere. Unless otherwise specified by the manufacturer, the spherical portion of the bearing block and the seat that holds this portion shall be cleaned and lubricated with a petroleum type oil such as motor oil at least every six months. The block shall be closely held in its spherical seat, but shall be free to tilt in any direction. A hardened metal bearing block shall be used beneath the specimen to minimize wear of the lower platen of the machine. To facilitate accurate centering of the test specimen in the compression machine, one of the two surfaces of the bearing blocks shall have a diameter or diagonal of between 2.83 in. [70.7 mm] (See **Note 3**) and 2.9 in. [73.7 mm]. When the upper block bearing surface meets this requirement, the lower block bearing surface shall be greater than 2.83 in. [70.7 mm]. When the lower block bearing surface meets this requirement, the diameter or diagonal of upper block bearing surface shall be between 2.83 and $3^1/_8$ in. [70.7 and 79.4 mm]. When the lower block is the only block with a diameter or diagonal between 2.83 and 2.9 in. [70.7 and 73.7 mm], the lower block shall be used to center the test specimen. In that case, the lower block shall be centered with respect to the upper bearing block and held in position by suitable means. The bearing block surfaces intended for contact with the specimen shall have a Rockwell harness number not less than 60 HRC. These surfaces shall not depart from plane surfaces by more than 0.0005 in. [0.013 mm] when the blocks are new and shall be maintained within a permissible variation of 0.001 in. or [0.025 mm].

Compression machine bearing blocks shall be checked for planeness in accordance with this test method at least annually using a straightedge and feeler stock and shall be refinished if found to be out of tolerance.

NOTE 3: The diagonal of a 2 in. [50 mm] cube is 2.83 in. [70.7 mm].

Chapter- 4

EXPERIMENTAL WORK

4.1 Materials

4.1.1 Graded Standard Sand:

The sand (**Note 4**) used for making test specimens shall be natural silica sand conforming to the requirements for graded standard sand in Specification **C778**.

NOTE 4: *Segregation of Graded Sand*—The graded standard sand should be handled in such a manner as to prevent segregation, since variations in the grading of the sand cause variations in the consistency of the mortar. In emptying bins or sacks, care should be exercised to prevent the formation of mounds of sand or craters in the sand, down the slopes of which the coarser particles will roll. Bins should be of sufficient size to permit these precautions. Devices for drawing the sand from bins by gravity should not be used.

4.2 Temperature and Humidity

Temperature–The temperature of the air in the vicinity of the mixing slab, the dry materials, molds, base plates, and mixing bowl, shall be maintained between 73.5 ± 5.5 °F or [23.0 ± 3.0 °C]. The temperature of the mixing water, moist closet or moist room, and water in the storage tank shall be set at 73.5 ± 3.5 °F or [23 ± 2 °C].

Humidity–The relative humidity of the laboratory shall be not less than 50 %. The moist closet or moist room shall conform to the requirements of Specification**C511**.

4.3 Test Specimens

Make two or three specimens from a batch of mortar for each period of test or test age.

4.4 Preparation of Specimen Molds

Apply a thin coating of release agent to the interior faces of the mold and non-absorptive base plates. Apply oils and greases using an impregnated cloth or other suitable means. Wipe the mold faces and the base plate with a cloth as necessary to remove any excess release agent and to achieve a thin, even coating on the interior surfaces. When using an aerosol lubricant, spray the release agent directly onto the mold faces and base plate from a distance of 6 to 8 in. or [150 to 200 mm] to achieve complete coverage. After spraying, wipe the surface with a cloth as necessary to remove any excess aerosol lubricant. The residue coating should be just sufficient to allow a distinct finger print to remain following light finger pressure (**Note 5**).

Seal the surfaces where the halves of the mold join by applying a coating of light cup grease such as petrolatum. The amount should be sufficient to extrude slightly when the two halves are tightened together. Remove any excess grease with a cloth.

Seal molds to their base plates with a watertight sealant. Use microcrystalline wax or a mixture of three parts paraffin wax to five parts rosin by mass. Paraffin wax is permitted as a sealant with molds that clamp to the base plate. Liquefy the wax by heating it to a temperature of between 230 and 248 °F or [110 and 120 °C]. Effect a watertight seal by applying the liquefied sealant at the outside contact lines between the mold and its base plate (**Note 6**).

Optionally, a watertight sealant of petroleum jelly is permitted for clamped molds. Apply a small amount of petroleum jelly to the entire surface of the face of the mold that will be contacting the base plate. Clamp the mold to the base plate and wipe any excess sealant from the interior of the mold and base plate.

NOTE 5: Because aerosol lubricants evaporate, molds should be checked for a sufficient coating of lubricant immediately prior to use. If an extended period of time has elapsed since treatment, retreatment may be necessary.

NOTE 6: *Watertight Molds*—The mixture of paraffin wax and rosin specified for sealing the joints between molds and base plates may be found difficult to remove when molds are being cleaned. Use of straight paraffin wax is permissible if a watertight joint is secured, but due to the low strength of paraffin wax it should be used only when the mold is not held to the base plate by the paraffin wax alone. When securing clamped molds with paraffin wax, an improved seal can be obtained by slightly warming the mold and base plate prior to applying the wax. Molds so treated should be allowed to return to room temperature before use.

4.5 Mix Design

As this research aim to keep similarity with the practical works, mix design used by the site engineer was collected by and calculated that has been demonstrated below.

Mix Design:-

Cement: Fine Aggregate: Coarse Aggregate = 1 : 1.25 : 2.5
Water Cement Ratio (W/C) = 0.4

Field Measurement:-

- In practical measurement they prefer to take measurement on volume basis.
- They use big bowl (Known as Korai in site) to take materials.
- We used a measuring box (Known as fery in site) of volume= (1*1*1.25)cft
  = **1.25 cft**
- **2.5 Korai** Materials were required to fill the **1.25 cft** fery.
- Weight of Fery = **12.2 kg**
- 1 bag cement is **50 kg** and it's volume is **1.25 cft**
- They use **6 korai** stone chips and **3.5 korai** sand for **50kg** cement.

Coarse aggregate (Stone Chips)

Weight of 1.25cft stone chips + box = 72 kg
Weight of 1.25cft stone chips = (72-12.2)kg
=**59.8kg**
Weight of Stone chips per Korai = (59.8/2.5)kg = 23.92 kg
Material volume per korai = (1.25/2.5)cft
= **.5 cft**

[*As they use 6 Korai stone chips for 50 kg cement*]

So,

Volume of 6 korai stone chips = (.5*6) cft = ***3 cft***

Weight of 6 korai stone chips = [(59.8*3)/1.25]= ***143.52 kg***

Fine Aggregate (Sand)

Weight of 1.25 sand + box =65.4 kg

Weight of 1.25 sand = (65.4-12.2) kg = **53.2 kg**

Weight of sand per Korai = (53.2/2.5) = 21.28 kg

Material volume per Korai = (1.25/2.5) = **.5cft**

[As they use 3.5 korai sand for 50kg cement**]**

So,

Volume of 3.5 Korai sand = (.5* 3.5) = ***1.75 cft***

Weight of 3.5 Korai Sand = [(53.2*1.75)/1.25]kg = ***74.48 kg***

<u>Actual ratio used in field</u>

Materials Proportion by Volume: - C: FA: CA = 1 : 1.4 : 2.4

Materials Proportion by Weight: - C: FA: CA= 1 : 1.49 : 2.87

1 : 1.5 : 3 (rounded)

4.6 Sieve Analysis

Table 4.1 : Sieve analysis

Sieve Opening (mm)	Sieve Wight (gm)	Total Weight(gm)	Material retained (gm)	%Material retained	Cumulative %retained	%Finer
4.75	561.5	561.5	0	0	0	100
2.36	529	564.5	35.5	2.4	2.4	97.6
1.18	495	715.5	220.5	14.7	17.1	82.9
0.6	483	1052.5	569.5	38	55.1	44.9
0.3	447.5	955.5	508	33.9	89	11
0.15	412	531	119	7.9	96.9	3.1
Pan	364	410	46	3.1	100	0
Total=			1498.5			

FM= 2.61

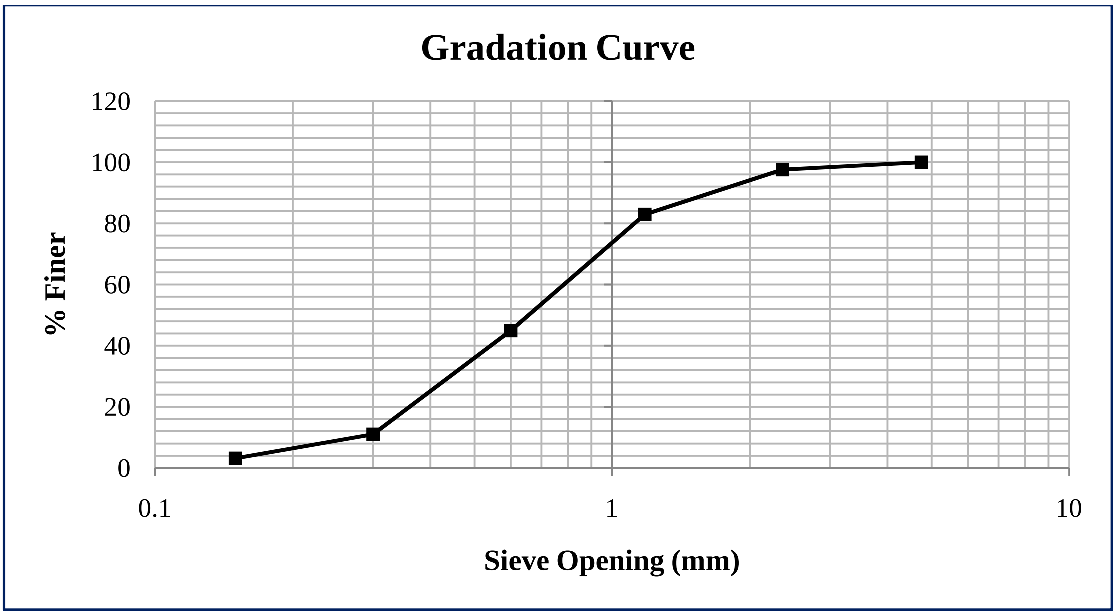


Figure : Gradation Curve

4.7 PROCEDURE

4.7.1 Composition of Mortars:

The proportions of materials for the standard mortar shall be one part of cement to 2.75 parts of graded standard sand by weight. Use a water-cement ratio of 0.485 for all portland cements and 0.460 for all air-entraining portland cements. The amount of mixing water for other than portland and air-entraining portland cements shall be such as to produce a flow of 110 ± 5 as determined in accordance with **10.3** and shall be expressed as weight percent of cement.

The quantities of materials to be mixed at one time in the batch of mortar for making six, nine, and twelve test specimens shall be as follows:

Number of Specimens	6	9	12
Cement, g	500	740	1060
Sand, g	1375	2035	2915
Water, mL			
Portland (0.485)	242	359	514
Air-entraining portland (0.460)	230	340	488

Other (to flow of 110 ± 5)	...	...	...

4.7.2 Preparation of Mortar:

Mechanically mix in accordance with the procedure given in Practice **C305**.

4.7.3 Determination of Flow:

Determine flow in accordance with procedure given in Test Method **C1437**.

For portland and air-entraining portland cements, merely record the flow.

In the case of cements other than portland or air-entraining portland cements, make trial mortars with varying percentages of water until the specified flow is obtained. Make each trial with fresh mortar.

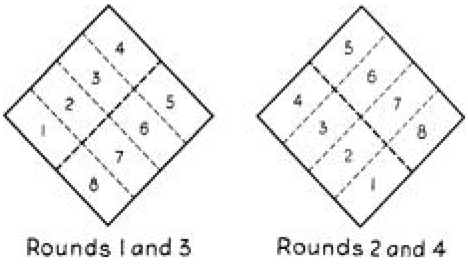
Immediately following completion of the flow test, return the mortar from the flow table to the mixing bowl. Quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl and then remix the entire batch 15 s at medium speed. Upon completion of mixing, the mixing paddle shall be shaken to remove excess mortar into the mixing bowl.

When a duplicate batch is to be made immediately for additional specimens, the flow test may be omitted and the mortar allowed to stand in the mixing bowl 90 s without covering. During the last 15 s of this interval, quickly scrape the bowl sides and transfer into the batch the mortar that may have collected on the side of the bowl. Then remix for 15 s at medium speed.

4.7.4. Molding Test Specimens:

Complete the consolidation of the mortar in the molds either by hand tamping or by a qualified alternative method. Alternative methods include but are not limited to the use of a vibrating table or mechanical devices.

Hand Tamping**—**Start molding the specimens within a total elapsed time of not more than 2 min and 30 s after completion of the original mixing of the mortar batch. Place a layer of mortar about 1 in. or [25 mm] (approximately one half of the depth of the mold) in all of the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 s in 4 rounds, each round to be at right angles to the other and consisting of eight adjoining strokes over the surface of the specimen, as illustrated in **Fig. 1**. The tamping pressure shall be just sufficient to ensure uniform filling of the molds. The 4 rounds of tamping (32 strokes) of the mortar shall be completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer. During tamping of the second layer, bring in the mortar forced out onto the tops of the molds after each round of tamping by means of the gloved fingers and the tamper upon completion of each round and before starting the next round of tamping. On completion of the tamping, the tops of all cubes should extend slightly above the tops of the molds. Bring in the mortar that has been forced out onto the tops of the molds with a trowel and smooth off the cubes by drawing the flat side of the trowel (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mold. Then, for the purpose of leveling the mortar and making the mortar that protrudes above the top of the mold of more uniform thickness, draw the flat side of the trowel (with the leading edge slightly raised) lightly once along the length of the mold. Cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion over the length of the mold.



Rounds 1 and 3 Rounds 2 and 4

Figure 4.1:- Order of Tamping in Molding of Test Specimens

Alternative Methods−Any consolidation method may be used that meets the qualification requirements of this section. The consolidation method consists of a specific procedure, equipment and consolidation device, as selected and used in a consistent manner by a specific laboratory. The mortar batch size of the method may be modified to accommodate the apparatus, provided the proportions maintain the same ratios as given in **10.1.2**.

Separate qualifications are required for the following classifications:
Class A, *Non-air entrained cements*—for use in concrete, such as sold under Specifications **C150**, **C595**, and **C1157**.
Class B, *Air-entrained cements*—for use in concrete, such as sold under Specifications **C150**, **C595**, and **C1157**.
Class C, *Masonry, Mortar and Stucco Cements*—such as sold under Specifications **C91**, **C1328**, and **C1329**.

An alternative method may only be used to test the cement types as given in above, for which it has been qualified.

It can also be used for Strength Activity Index determinations for fly ash and slag, such as sold under Specifications **C618** and **C989**, provided the alternative method has qualified for both Class A and Class C cements.

Qualification Procedure−Contact CCRL to purchase cement samples that have been used in the Proficiency Sample Program (PSP). Four samples (5 Kg each) of the class to be qualified will be required to complete a single qualification (See **Note 7**).

In one day, prepare replicate 6-cube or 9-cube batches using one of the cements and cast a minimum of 36 cubes. Complete one round of tests on each cement on different days. Store and test all specimens as prescribed in the sections below. Test all cubes at the age of 7-days.

Tabulate the compressive strength data and complete the mathematical analyses as instructed in **Annex A1**.

Requalification of the Alternate Compaction Method:

Requalification of the method shall be required if any of the following occur:

(1) Evidence that the method may not be providing data in accordance with the requirements of **Table 4.2**

Table 4.2 :- Precision

	Test Age, days	Coefficient of Variation, 1*s* %[A]	Acceptable Range of Test Results,*d*2*s* %[A]
Portland Cements			
Constant water-cement ratio:			
Single laboratory	1	3.1	8.7
	3	3.9	10.9
	7	3.9	10.9
	28	3.8	10.6
Average	...	3.7	10.4
Multiple laboratories	1	7.3	20.4
	3	6.8	19.0
	7	6.6	18.5
	28	6.5	18.2
Average	...	6.6	18.5
Blended Cements			
Constant flow mortar:			
Single laboratory	3	4.0	11.3

	Test Age, days	Coefficient of Variation, 1*s* %[A]	Acceptable Range of Test Results,*d*2*s* %[A]
	7	3.8	10.7
	28	3.4	9.6
Average	...	3.8	10.7
Multiple laboratories	3	7.8	22.1
	7	7.6	21.5
	28	7.4	20.9
Average	...	7.6	21.5
Masonry Cements			
Constant flow mortar:			
Single laboratory	7	7.9	22.3
	28	7.5	21.2
Average	...	7.7	21.8
Multiple laboratories	7	11.8	33.4
	28	12.0	33.9
Average	...	11.9	33.7

(A) These numbers represent, respectively, the (1*s* %) and (*d*2*s* %) limits as described in Practice **C670**.

(2) Results that differ from the reported final average of a CCRL-PSP sample with a rating of 3 or less.

(3) Results that differ from the accepted value of a known reference sample with established strength values by more than twice the multi-laboratory 1s% values of **Table 4.2**

Before starting the requalification procedure, evaluate all aspects of cube fabrication and testing process to determine if the offending result is due to some systematic error or just an occasional random event.

If the compaction equipment is replaced, significantly modified, repaired, or has been recalibrated, requalify the equipment in accordance with above.

NOTE 7: It is recommended that a large homogenous sample of cement be prepared at the time of qualification for use as a secondary standard and for method evaluation. Frequent testing of this sample will give early warning of any changes in the performance of the apparatus.

4.7.5 Storage of Test Specimens

Immediately upon completion of molding, place the test specimens in the moist closet or moist room. Keep all test specimens, immediately after molding, in the molds on the base plates in the moist closet or moist room from 20 to 72 h with their upper surfaces exposed to the moist air but protected from dripping water. If the specimens are removed from the molds before 24 h, keep them on the shelves of the moist closet or moist room until they are 24-h old, and then immerse the specimens, except those for the 24-h test, in saturated lime water in storage tanks constructed of noncorroding materials. Keep the storage water clean by changing as required.

4.7.6 Determination of Compressive Strength:

Test the specimens immediately after their removal from the moist closet in the case of 24-h specimens, and from storage water in the case of all other specimens. All test specimens for a given test age shall be broken within the permissible tolerance prescribed as follows:

Test Age	Permissible Tolerance
24 h	$\pm {}^{1}/_{2}$ h
3 days	± 1 h
7 days	± 3 h
28 days	± 12 h

If more than one specimen at a time is removed from the moist closet for the 24-h tests, keep these specimens covered with a damp cloth until time of testing. If more than one specimen at a time is removed from the storage water for testing, keep these specimens in water at a temperature of 73.5 ± 3.5 °F or [23 ± 2 °C] and of sufficient depth to completely immerse each specimen until time of testing. Wipe each specimen to a surface-dry condition, and remove any loose sand grains or incrustations from the faces that will be in contact with the bearing blocks of the testing machine. Check these faces by applying a straightedge (**Note 8**). If there is appreciable curvature, grind the face or faces to plane surfaces or discard the specimen. A periodic check of the cross-sectional area of the specimens should be made.

NOTE 8: *Specimen Faces*—Results much lower than the true strength will be obtained by loading faces of the cube specimen that are not truly plane surfaces. Therefore, it is essential that specimen molds be kept scrupulously clean, as otherwise, large irregularities in the surfaces will occur. Instruments for cleaning molds should always be softer than the metal in the molds to prevent wear. In case grinding specimen faces is necessary, it can be accomplished best by rubbing the specimen on a sheet of fine emery paper or cloth glued to a plane surface, using only a moderate pressure. Such grinding is tedious for more than a few thousandths of an inch (hundredths of a millimetre); where more than this is found necessary, it is recommended that the specimen be discarded.

Apply the load to specimen faces that were in contact with the true plane surfaces of the mold. Carefully place the specimen in the testing machine below the center of the upper bearing block. Prior to the testing of each cube, it shall be ascertained that the spherically seated block is free to tilt. Use no cushioning or bedding materials. Bring the spherically seated block into uniform contact with the surface of the specimen. Apply the load rate at a relative rate of movement between the upper and lower platens corresponding to a loading on the specimen with the range of 200 to 400 lbs/s [900 to 1800 N/s]. Obtain this designated rate of movement of the platen during the first half of the anticipated maximum load and make no adjustment in the rate of movement of the platen in the latter half of the loading especially while the cube is yielding before failure.

NOTE 9: It is advisable to apply only a very light coating of a good quality, light mineral oil to the spherical seat of the upper platen.

4.7.7 Porosity test

When fresh mortar is transferred from a trowel onto bricks or blocks, the rheology of the mortar changes immediately as water is drawn out by suction. The objective of the project was investigate how this affects the mortar microstructure and, in particular, whether the initial air content of mortar in the plastic state, based on measurements from a pressure device (eg: BS EN 1015-7:1999), can be related to the porosity of hardened mortar using petrographic methods.

Porosity of cement mortar cube was tested for both OPC and CPC cement. Porosity was determine using following Equation

$$\text{Porosity (\%)} = (\text{Wssd} - \text{Wod})/(\text{Wssd} - \text{Wwater})\ldots\ldots\ldots(6)$$

Where, Wssd= weight of sample in SSD condition

Wod= Weight of sample in OD condition

Wwater = Weight of sample in water

Chapter - 5

RESULTS AND DISCUSSION

5.1. Compressive strength and Porosity Determination

5.1.1. Porosity (Case-1: PCC Cement Mortar and porosity determination by keeping the samples on air)

The data and results have been found from this experiment for porosity are given below

Table 5.1: Data for Porosity test

Sample No	Curing age (days)	Porosity %	Total age (days)	Corresponding Porosity %	Total age (days)	Corresponding Porosity %
1	4	20.185	42	16.813	84	15.998
2	7	19.513	42	17.210	84	16.194
3	10	18.821	42	17.137	84	16.037
4	14	15.926	42	16.790	84	16.082
5	21	18.657	42	17.007	84	15.771
6	28	18.929	42	16.539	84	15.619

From Table 1 it is noticed that with the increase of age of cement mortar the porosity decreases gradually. For sample (1) the porosity was 20.185% at the age of 4 days and it reduces to 16.813% and 15.998% at age of 42 and 84 days respectively. This is same phenomenon for rest of the samples designated (2), (3), (v) and (6). But the sample designated (4) show a different result. After 14 days curing, the sample gets porosity of 15.926% and its porosity increases to 16.79% at the age of 42 days. This irregular trend of increasing porosity instead of decreasing is considered as human error. This may be caused by erroneous weight taking of sample. Again at 84 days the sample decreases its porosity to 16.082% from 16.79%. This represents that, as error was not present in taking weight, so the same sample gets decreasing trend of porosity.

The graphical presentations are given below:

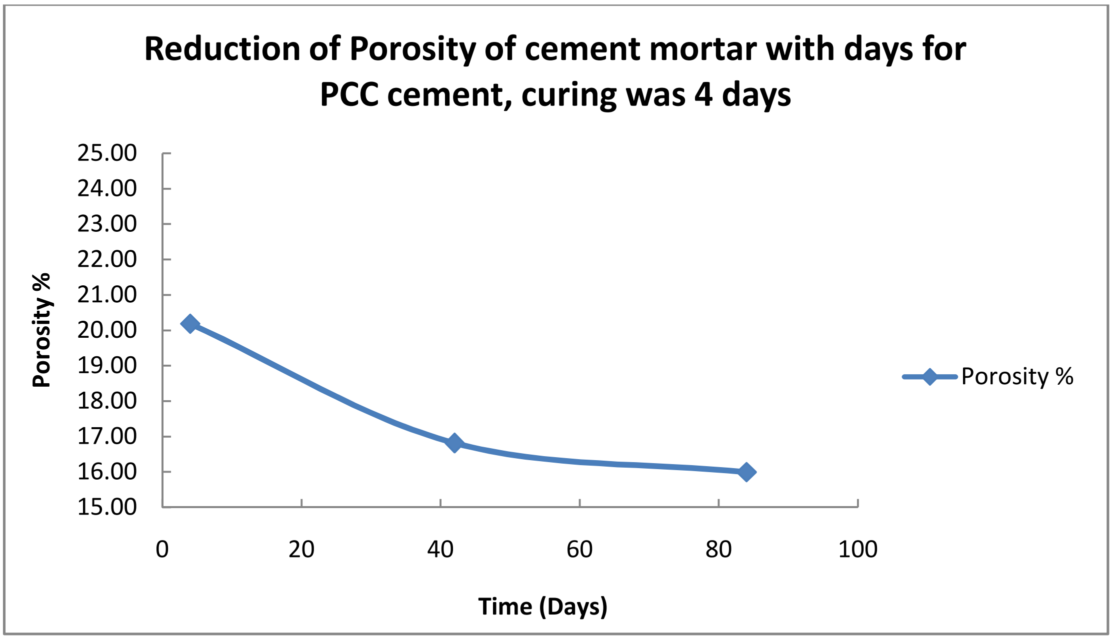


Figure 5.1:- Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-1)

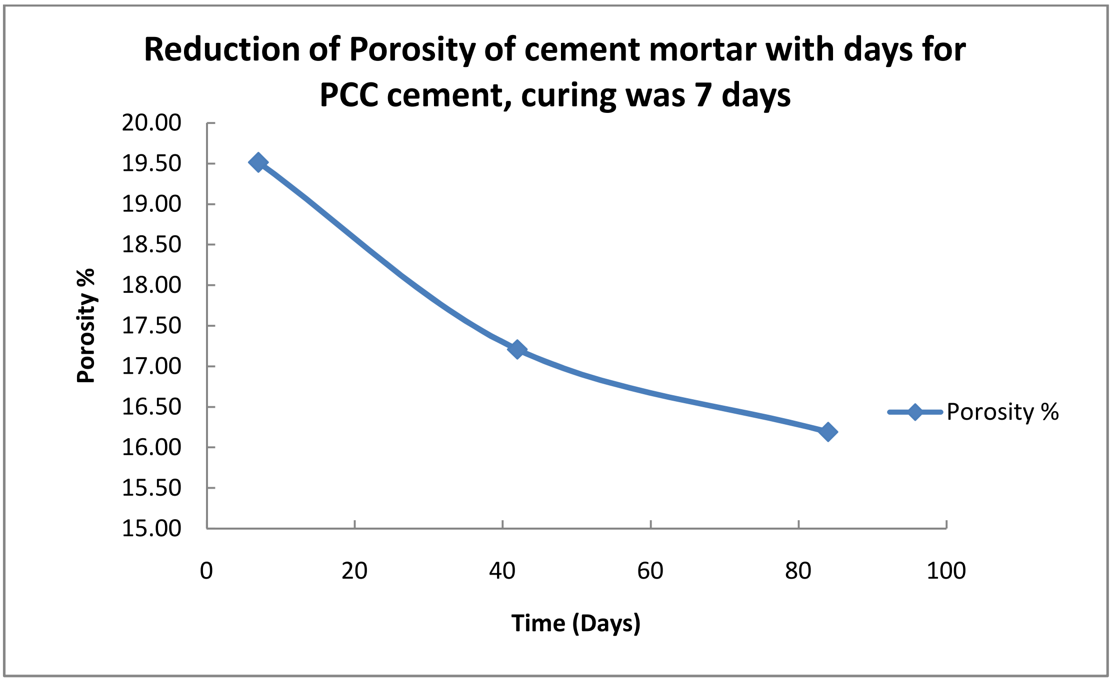


Figure 5.2 : - Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-2)

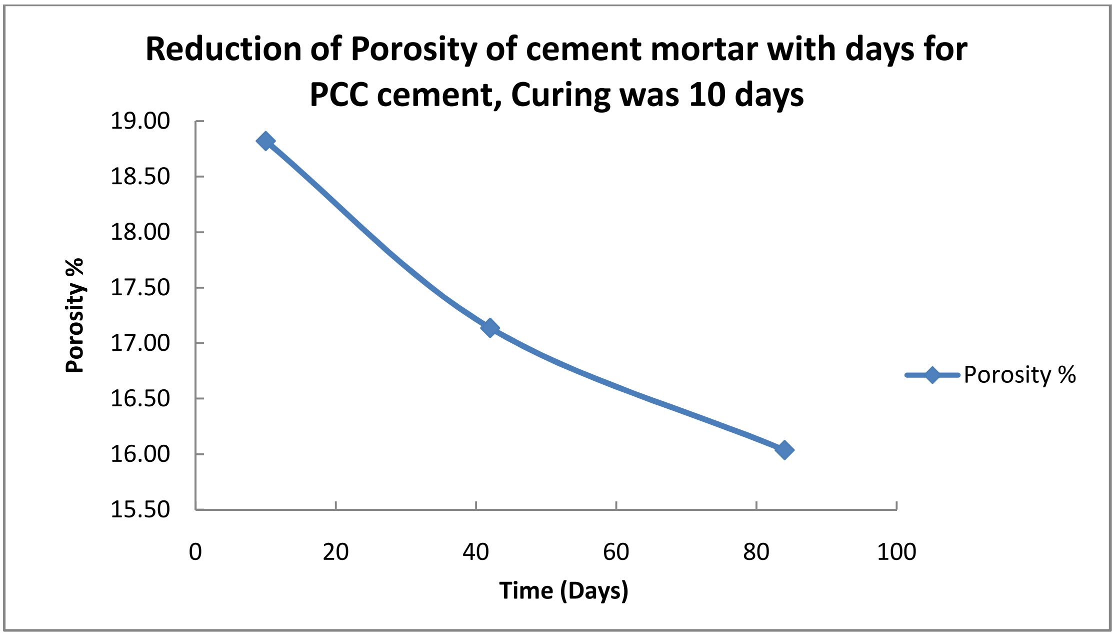


Figure 5.3 :- Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-3)

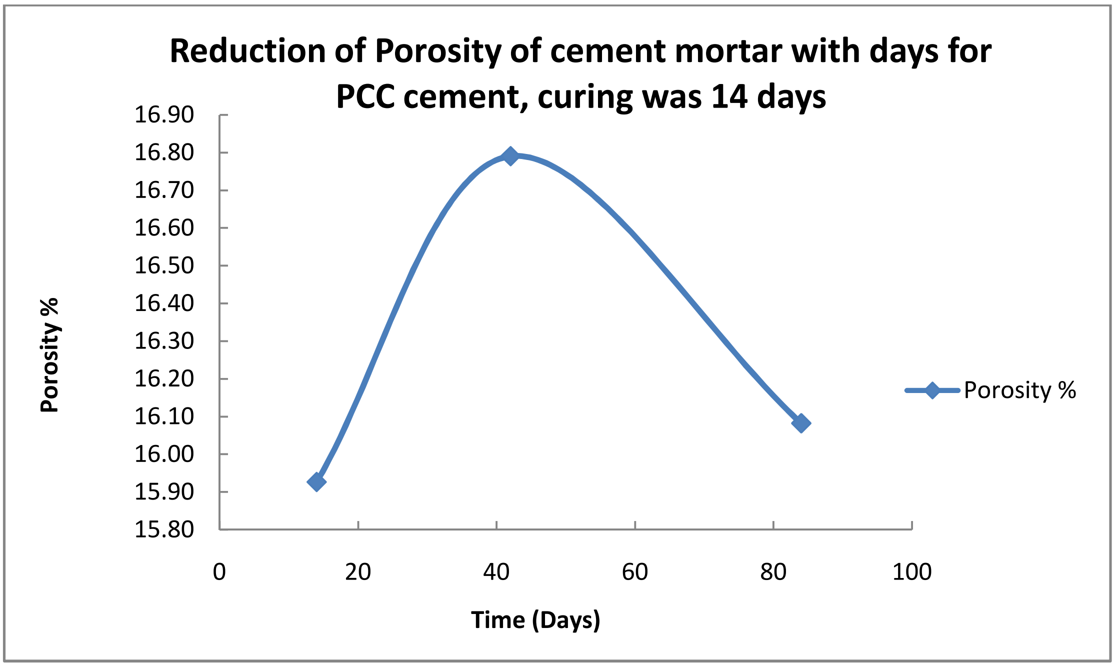


Figure 5.4 :- Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-4)

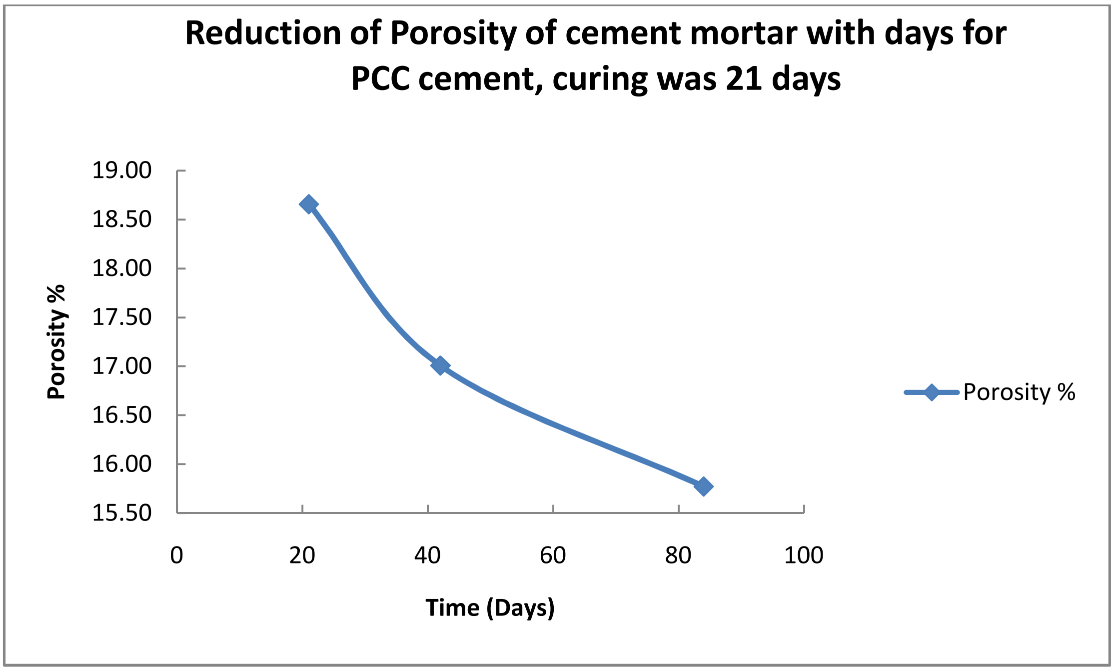


Figure 5.5 :- Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-5)

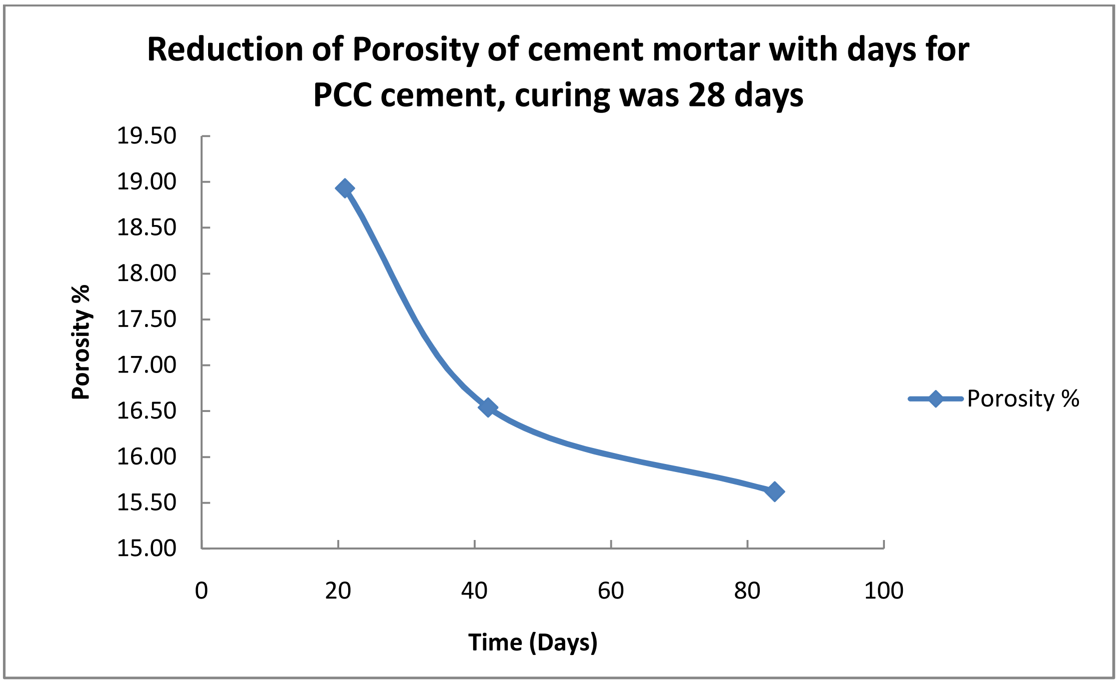


Figure 5.6 :- Porosity Reduction of Cement Mortar with Days for PCC Cement (sample-6)

From the above Figure we can see that Figure 5 to Figure 10 shows that with increasing in age of sample the porosity is decreasing except Figure 8 (sample 4). Figure 8 is considerable as human error. Again it is observed in Figure 8, the curve is parabolic that means firstly it is increasing and then decreasing. If the first point is ignored then the porosity is decreasing with time.

5.1.2 Compressive strength (Case -1 : Compressive strength determined for OPC and PCC cement mortar for Oven dry and Saturated surface dry condition)

Below the Table show the experimental data that have been obtained. These data has been plotted on graph and the findings are below.

Table 5.2 : Data Table

Cement type	Time (days)	Strength psi (OD)	Strength psi (SSD)
OPC	3	5110.6	4619.7
	14	6821.8	5445.2
	28	6573.9	5551.8
	42	7935.4	5821.1
	56	8654.3	6280.5
PCC	3	4347.5	2787.8
	14	6078.6	3772.3
	28	7372.2	5842.8
	42	7074.2	7304.4
	56	8180.1	6987.7

From the Figure 5.7 it is seen that the curve for compressive strength of cement mortar of OPC cement in OD condition is uprising. But it is noticeable that the compressive strength at age of 28 days has deflected from its continuous trend. This error value is because of human error. This human error may be caused by inhomogeneous tamping, disturbed in curing and other to happen. But it has hardly possibility to get change in w/c ratio.So ignoring the human error is showing the increasing trend of compressive strength of OPC cement with increased age. The compressive strength for SSD condition of OPC cement shows a regular increasing curve.

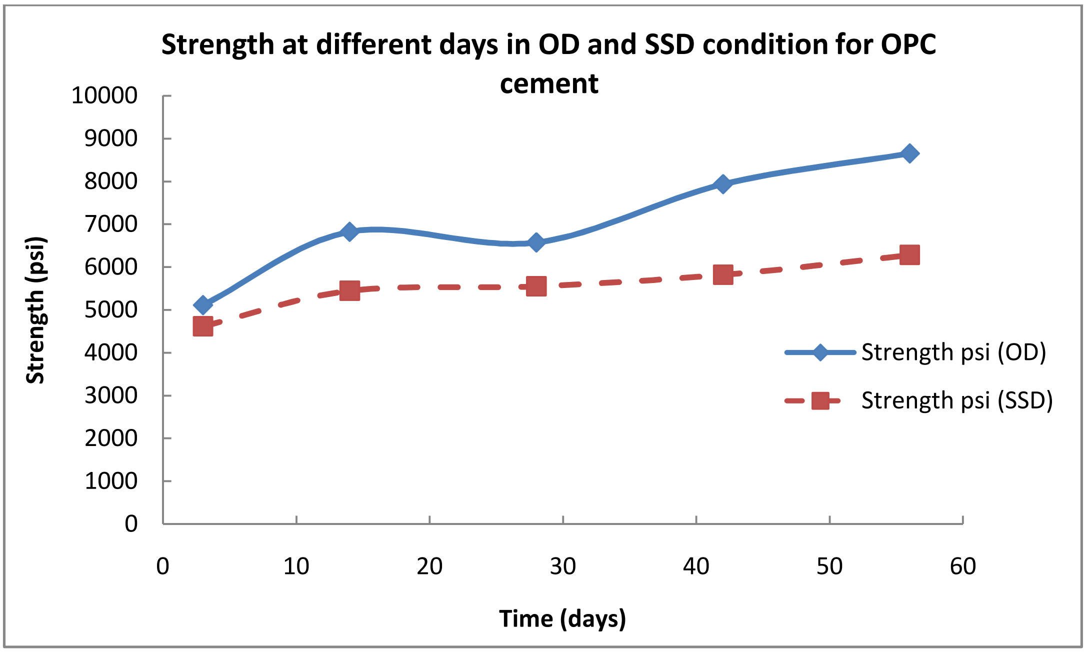


Figure 5.7: Strength at different days in OD and SSD condition for OPC cement

It is also found that the compressive strength curve for OD condition is above the curve for SSD condition. This means that the compressive strength for a particular sample, the strength in OD condition has a higher value than strength in SSD condition. Figure 5.8 represents the curves for the PCC cement mortar in OD and SSD condition are uprising. But here also exist deflected data in OD condition at the age of 42 days and in SSD condition at the age of 56 days. These data are considered as human error. In practical sense, ignoring the human error is not a big deal as the required compressive strength of cement mortar is gained by 28 days according the specification of cement as used.

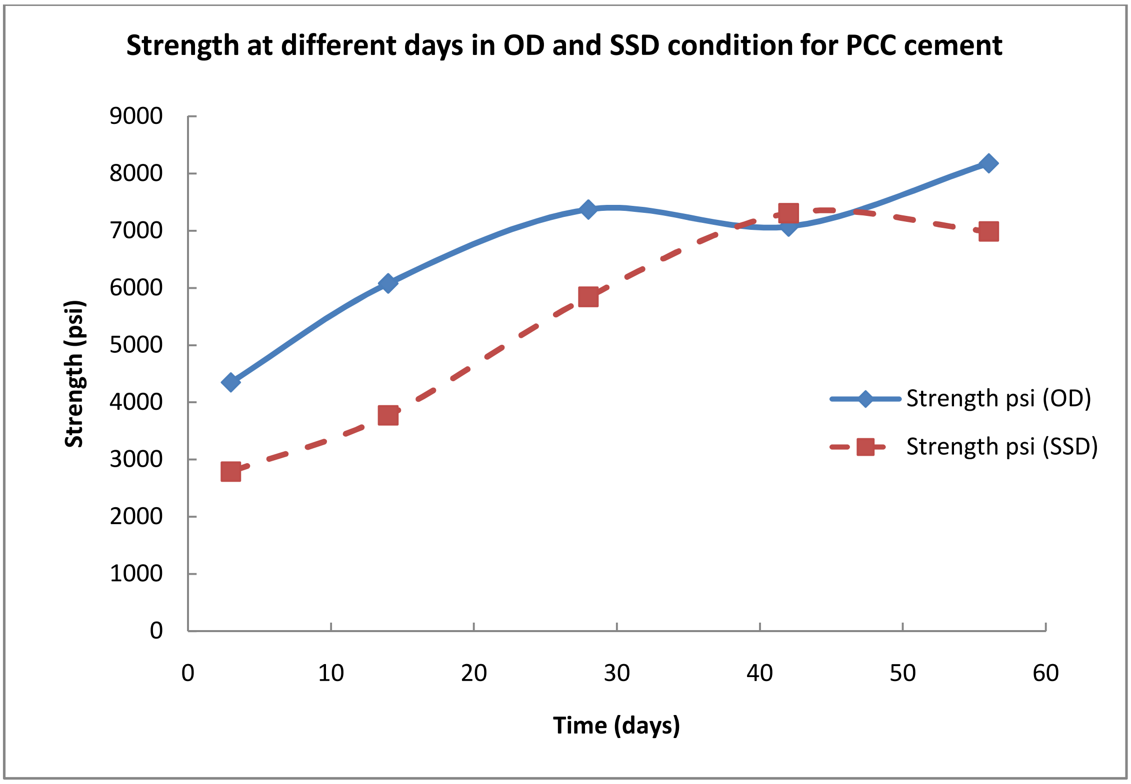


Figure 5.8: Strength at different days in OD and SSD condition for PCC cement

Figure 5.9 and Figure 5.10 representing comparative compressive strength in OD and SSD condition respectively for OPC and PCC cement mortar for different days. This research reveals that OPC cement gives earlier aged high strength than PCC cement. Figure 5.9 shows that at the age of 3 days for OD condition, strength for OPC cement is 5111psi where PCC cement gains 4348 psi. But at 56 days the strength for both OPC and PCC cement is approximately same.

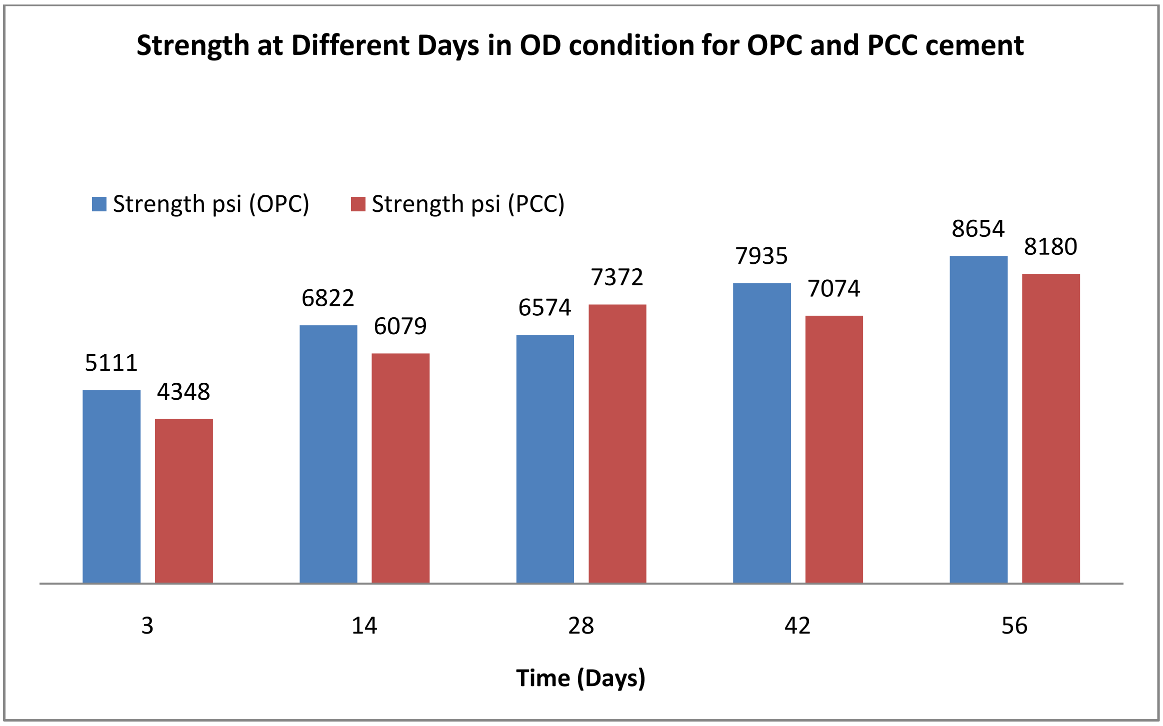


Figure 5.9 : Strength at different days in OD condition for OPC and PCC cement

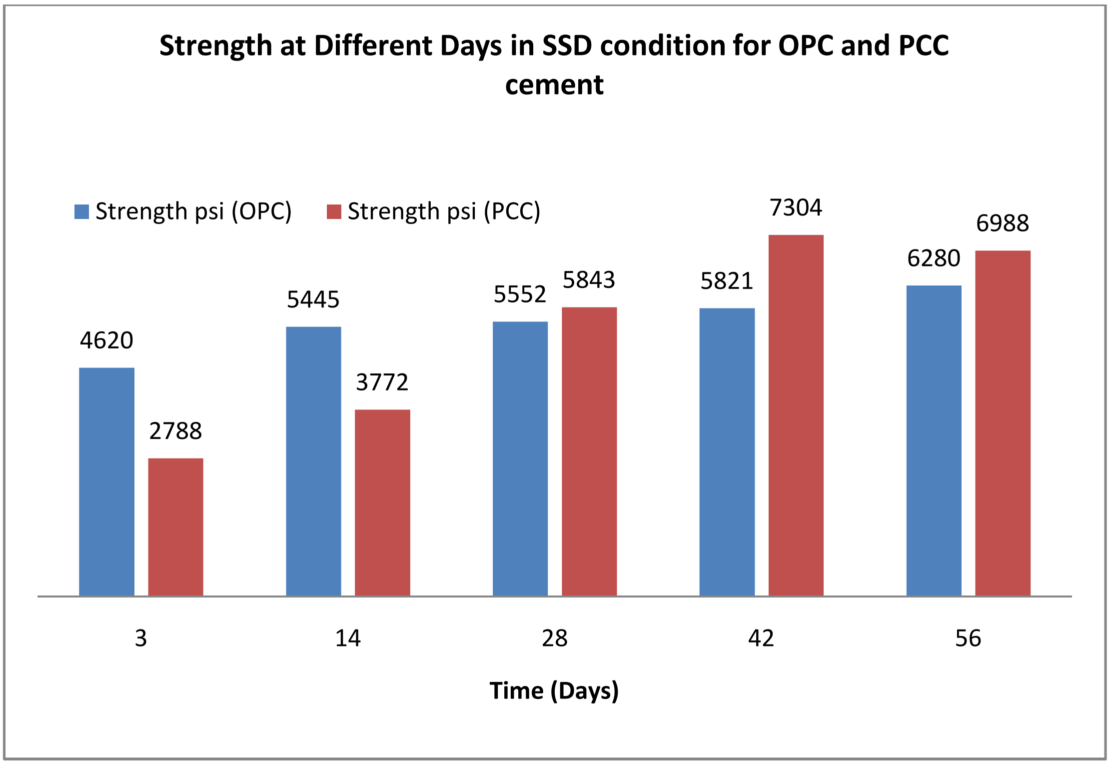


Figure 5.10: Strength at different days in SSD condition for OPC and PCC cement

As it is noticeable in Figure 10 that difference between strengths in SSD condition for OPC and PCC cement is significant at age of 3 days. OPC cement gains 4620 psi at 3 days whereas PCC gains 2788 psi. But at later age PCC cement gains higher strength than OPC. PCC cement gains 6988 psi at 56 days whereas OPC gains 6280 psi.

5.1.3 Porosity (Case-2: OPC and PCC Cement Mortar and porosity determination by keeping the samples on air)

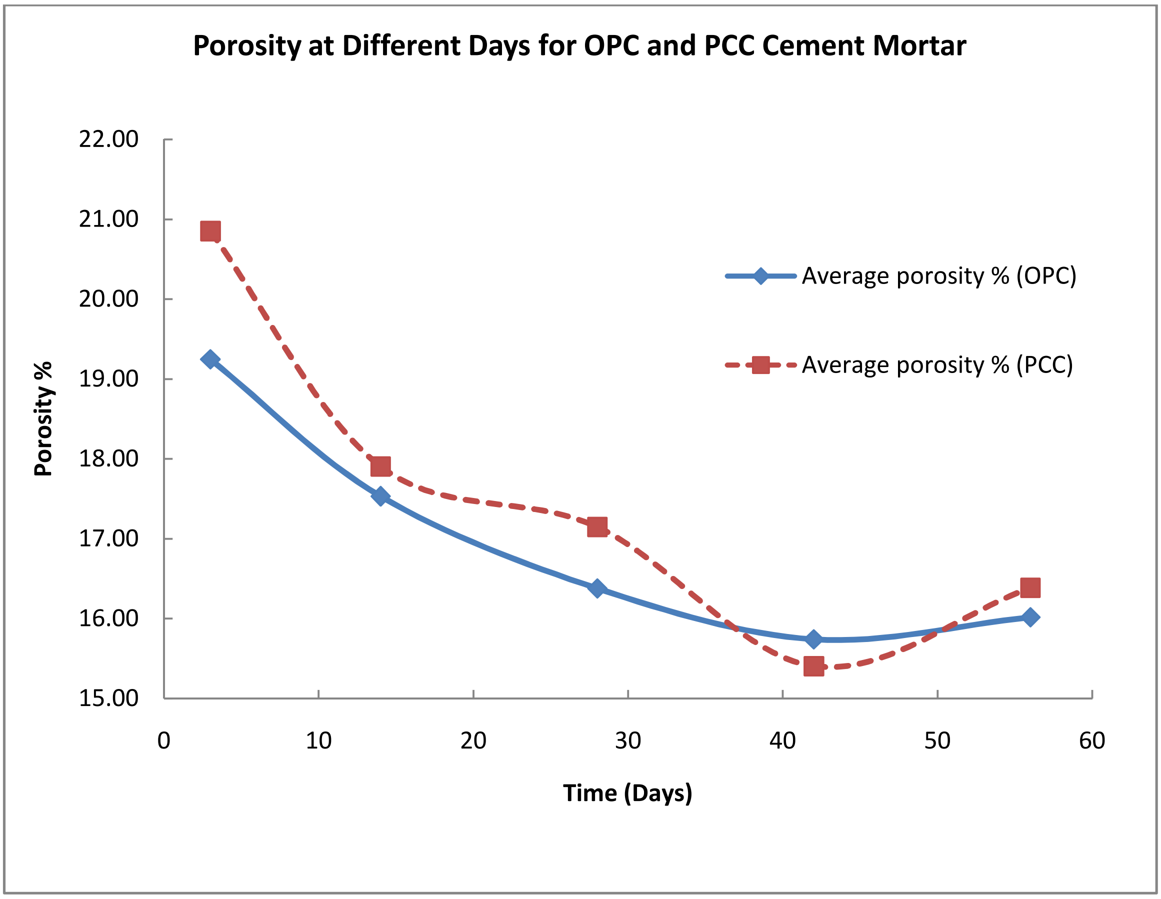


Figure 5.11 :- Porosity at different days for OPC and PCC cement Mortar

From the Figure above we can comprise the development of porosity for OPC and PCC cement for a particular day. It is found that the curve for PCC cement is above the curve for OPC cement. This indicate that PCC cement mortar have greater porosity value than OPC cement. It is noticeable for the 42 days that porosity for PCC is less than OPC cement. This result can be ignored as human error.

To ensure the behavior of OPC and PCC cement strength gain pattern, another casting was done to make the cross check with previous data.

5.1.4 Compressive Strength (Case-2: Compressive strength determined for OPC and PCC cement mortar for Saturated surface dry condition)

Table 5.3 :- Strength at different days of Cement mortar for OPC and PCC cement

Time (Days)	Strength For PCC Cement (psi)	Strength For OPC Cement (psi)
3	3394.14	3469.65
14	5161.16	4722.22
21	5855.12	4998.46
28	6014.40	4896.51

The table above shows the data has acquired from the experiment. These data has been plotted on graph shown below. It is demonstrated that two curves and their respective trend line has been shown. Both for OPC and PCC cement the compressive strengths of Cement Mortar are increasing trend. These two curves are showing very distinctive manner. From chart, the trend ling for PCC cement started from a lower point of tread line for OPC cement. Starting point of tread line means the earlier age of cement Mortar. So these trend lines represent that for earlier age the cement mortar,

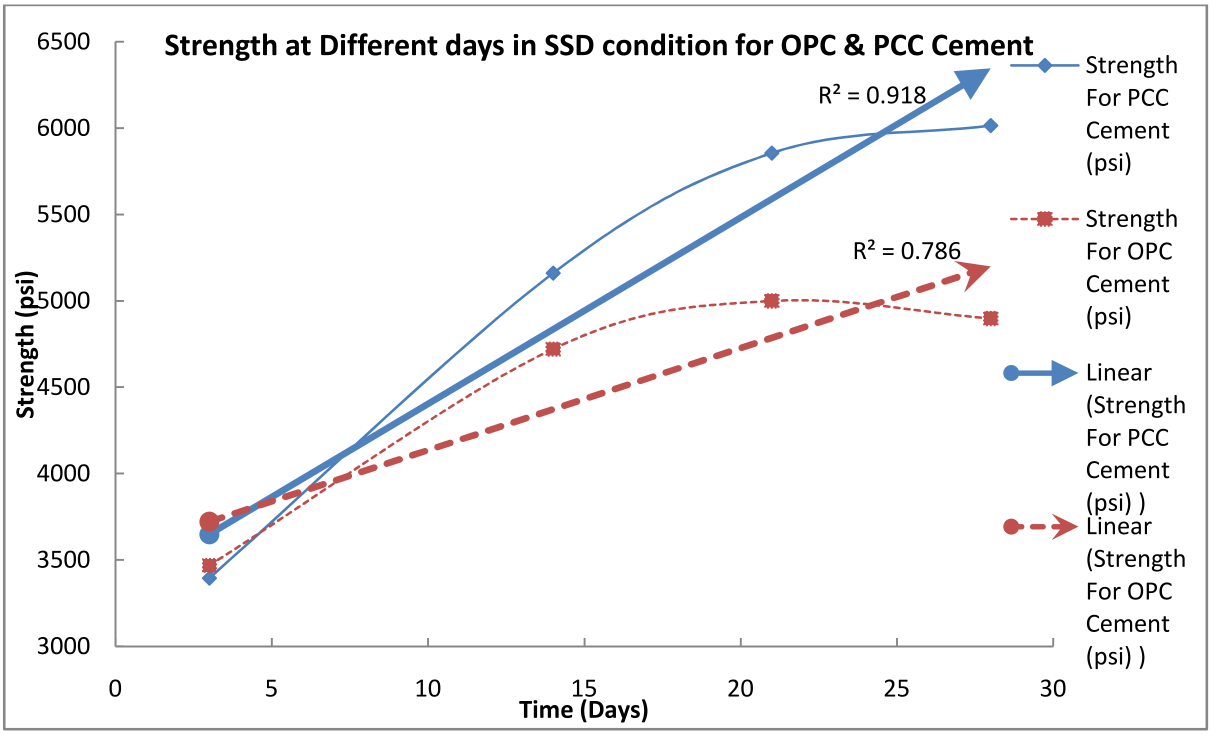


Figure 5.12 :- Strength at Different days in SSD condition for OPC & PCC Cement

OPC cement gives higher strength than PCC cement. After a certain age cement mortar for both cements gets same strength for a certain age according the trend line in Figure . After that crossing point the trend line for OPC cement is below the trend line of PCC cement. And their distance increases with the increase of age of cement mortar. This presenting that the later age strength of cement mortar for PCC cement is higher than OPC cement.

5.1.5 Porosity (Case-3 : OPC and PCC Cement Mortar and porosity determination by keeping the samples into water)

Table 5.4 : - Compressive strength and corresponding Percent of Porosity for different days of OPC and PCC cement.

Time (Days)	Strength For PCC Cement (psi)	Corresponding Porosity for PCC Cement Mortar (%)	Strength For OPC Cement (psi)	Corresponding Porosity for OPC Cement Mortar (%)
3	3394.14	18.22	3469.65	18.45
14	5161.16	16.73	4722.22	17.39
21	5855.12	17.24	4998.46	16.42
28	6014.40	16.23	4896.51	16.67

For the higher value of compressive strength percent of porosity reduces. Graphical presentation has been shown in below.

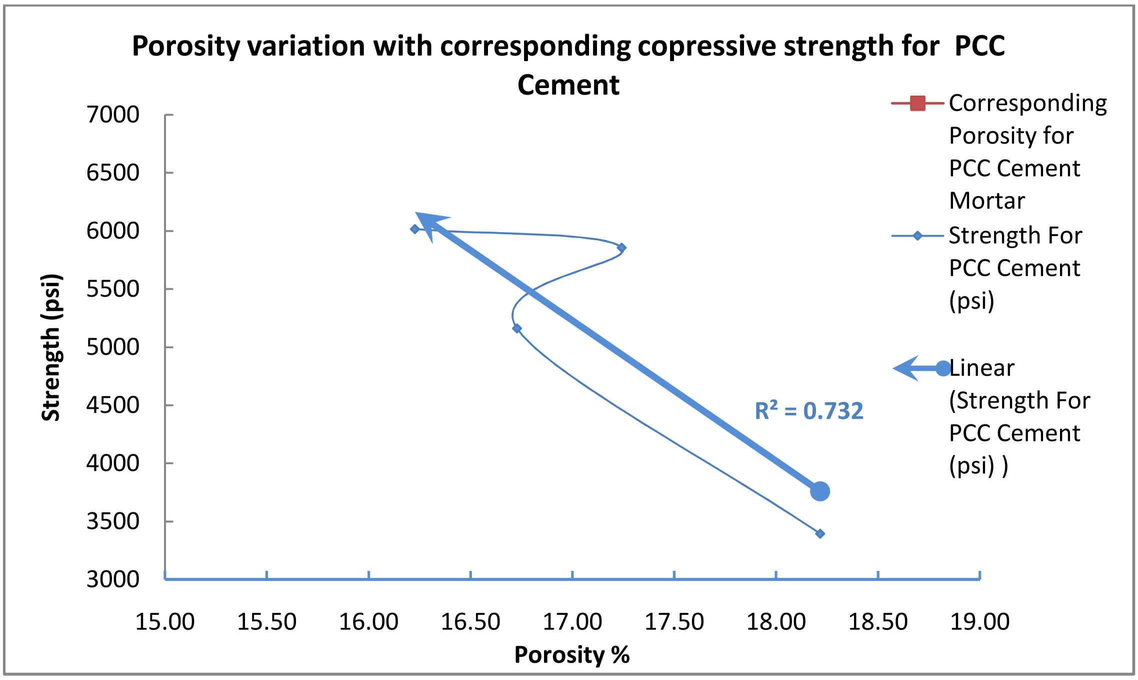


Figure 5.13 :- Porosity variation with corresponding compressive strength for PCC Cement Mortar

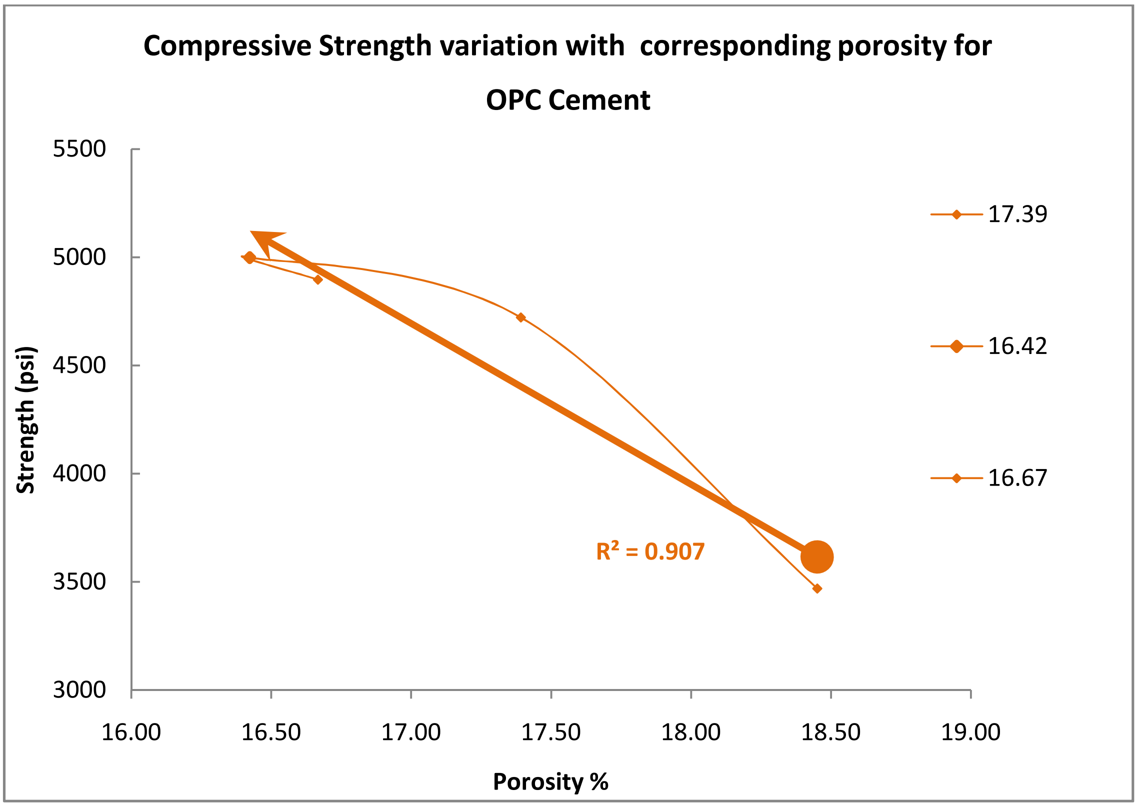


Figure 5.14:- Porosity variation with corresponding compressive strength for OPC Cement Mortar

In Figure 5.13 and Figure 5.14 it is indicated that the curves are in decreasing trend with the increase in Compressive strength of cement mortar. Both OPC and PCC cement mortar show that with the increase of compressive strength, Porosity decreases. In fact because of less porous characteristics, compressive strength increases.

5.1.6 Porosity (Case-4: OPC and PCC cement mortar and porosity determined by 5 hour boiling)

These casting was conducted with w/c of 0.3 and super plasticizer or water reducer was used. When the data were collected for the determination of porosity then the samples were crossed age of 28 days. This means that samples had enough age to get ultimate strength.

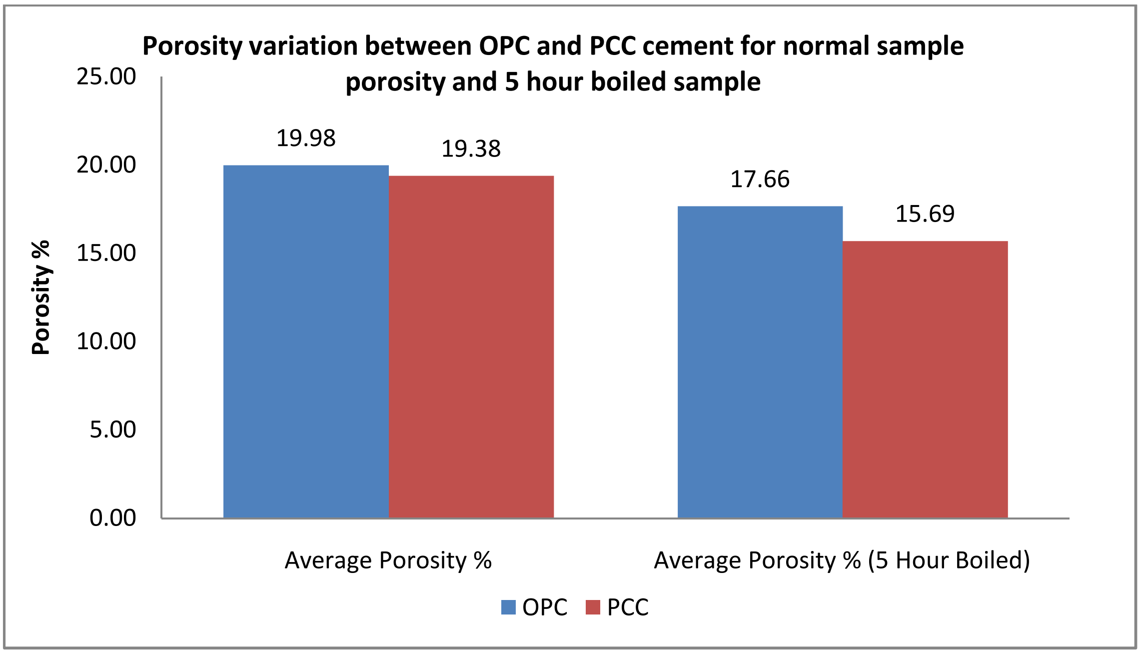


Figure 5.15: - Porosity Variation between OPC and PCC cement for normal sample porosity and 5 hour boiled sample.

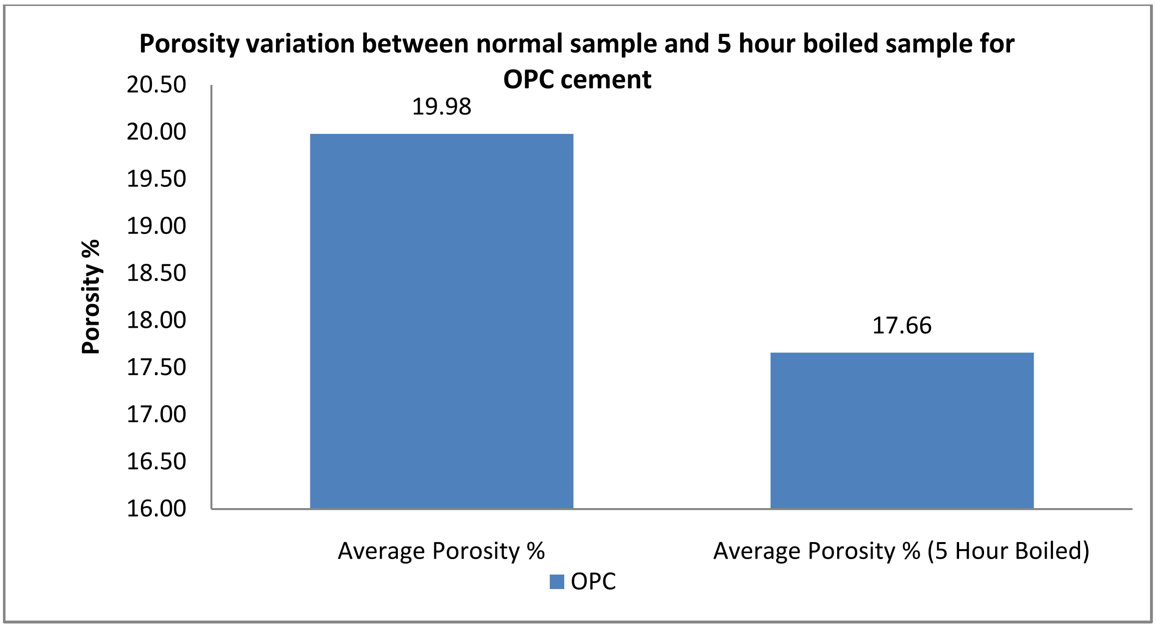


Figure 5.16: - Porosity variation between normal sample and 5 hour boiled sample for OPC cement.

From Figure 5.15, comparison between OPC and PCC cement for average porosity (normal sample) and 5 hour boiled sample has been shown. Here it noticed that OPC cement mortar have got larger value of percent porosity than the PCC cement mortar.

Same phenomenon has been observed for average porosity of normal sample as well as for 5 hour boiled sample.

Finding has been documented in this researches that boiling water have influence in reduction of Porosity. Reduction in porosity causes increase in compressive strength. From Figure 5.16, it is demonstrated for OPC cement, average porosity for normal sample has a higher value than 5 hour boiled sample. 5 hour boiled sample with lower percent porosity represents the higher value of compressive strength.

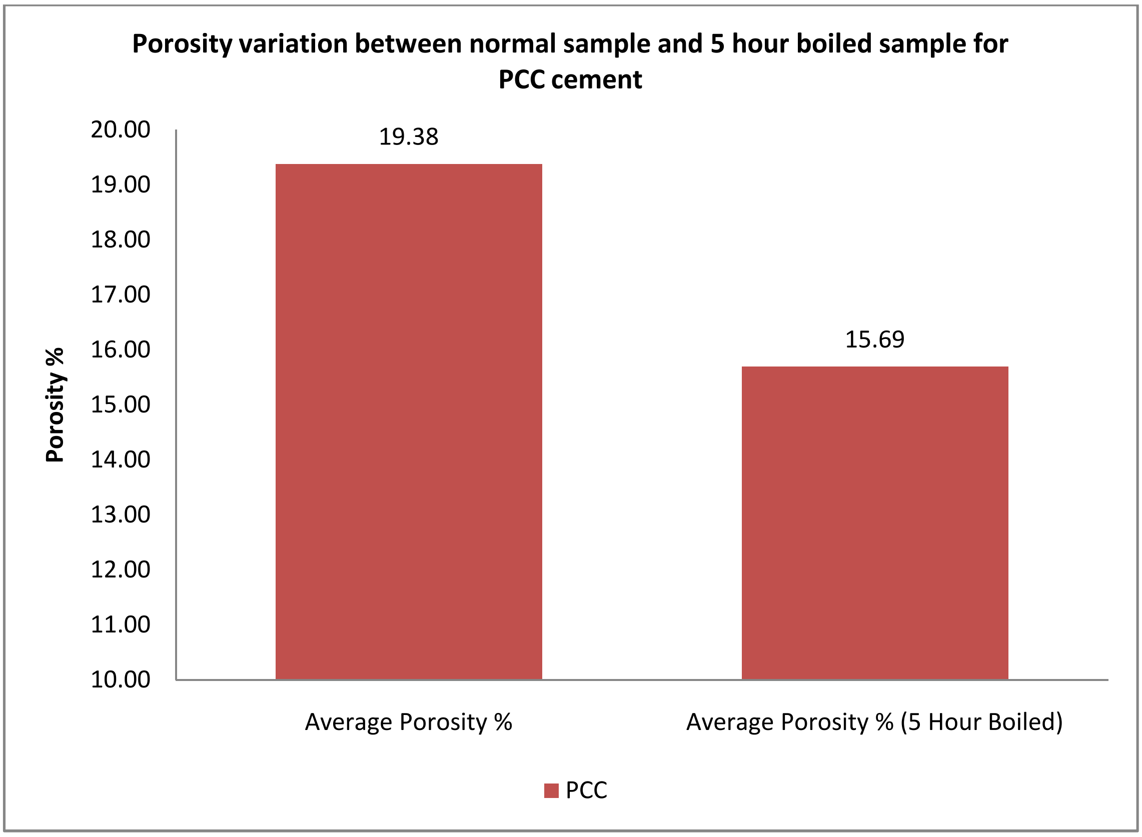


Figure 5.17: - Porosity variation between normal sample and 5 hour boiled sample for PCC cement.

Same phenomenon has been shown in Figure 5.17 as like as Figure 5.16. Here 5 hour boiled samples belong percent porosity which is less than porosity of normal sample for PCC cement mortar.

Chapter-6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Micro structure characteristics of concrete control the service life and longevity of concrete structure. Materials transport properties like permeability and diffusivity are controlled by micro structure characteristics of concrete. Absorption, workability, porosity, type occupancy and surrounding environment have a good influence on concrete structure.

The main objectives of this research was to determine the relation between OPC and PCC cement strength and their corresponding porosity as well as temperature effect on cement mortar. To keep pace with the practical field work, materials were from construction site. Researchers also tried to keep the same environment as like as work field.

This research was completed in several Cases. One finding was cross-checked by further experiments. For porosity 4 Cases were maintained and for compressive strength 2 cases were done. Case-1 was done with PCC cement and only porosity change was determined with increasing age. And results show that with the increase of cement mortar age porosity decreases gradually. After a certain age, porosity reduction rate decrease. Porosity Case-2 was to use for the cross-check of Case -1 as well as porosity change trend difference for OPC and PCC cement. Case -2 shows the same type of results like Case-1 regarding porosity reduction. PCC cement Mortar represents higher percent porosity than OPC cement mortar. Porosity Case-1 and Case-2 both samples were kept in air after their first level porosity determination. For Porosity Case-3, same procedure was maintained expect that sample were kept into water after first level porosity determination. Porosity Case-3 determines the porosity reduction when the cement mortar is into water. Porosity Case-4 have different condition as it’s w/c ratio is 0.3 and it’s porosity determined in normal condition as well as after boiling the samples 5 hours in 100◦C temperature. Results shows those 5 hours boiling samples have less porosity than normal condition. So this may documented that temperature have reduction influence on cement mortar.

For the compressive strength 2 Cases or steps were followed. Case-1 and Case-2 were same in procedure. Case-2 was done to cross- check to Case-1. Additional was to determine OD condition compressive strength of for Case-1. Case-1 shows that compressive strength for OD condition is higher than SSD condition. Another finding is that compressive strength for OPC cement is higher in earlier age than PCC cement. On the other hand compressive strength for PCC cement is higher than OPC cement in later age. This way of strength gains for OPC and PCC cement is same for both OD and SSD condition.

6.2 Recommendation

- Collection of materials was difficult to collect as small amount. So University authority should provide help regarding this issue.
- Because of holidays, sometimes it was difficult to take data reading from lab. So data taking date should have to fix such way to avoid holidays.
- Working time on lab is limited. So authority should plan to increase the working time.

References

[1] Mehta, P. K. and Monteiro, P. J. M. *Concrete: microstructure, properties, and materials*, 3rd ed. 2006, New York: McGraw-Hill, 659 p.

[2] Martys, N.S. *Survey of concrete transport properties and their measurement*, NISTIR 5592, US Department of Commerce, 1996, p. 1–40.

[3] Drazan, J. and Zelic, J. The effect of fly ash on cement hydratıon in aqueous suspensions, Ceramics−Silikaty, 2006, **50**(2): 98-105.

[4] Yilmaz, B. Olgun, A. *Studies on cement and mortar containing low-calcium fly ash, limestone, and dolomitic limestone*, Cement Concrete Compos. 2008, **30**: 194-201.

[5] Worrell, E., Martin, N. and Price, L. *Potentials for energy efficiency improvement in the US cement industry*, Energy, 2000, **25**(12): 1189-1214.

[6] Fu, X., Wang, Z., Tao, W., Yang, C., Hou, W., Dong, Y. and Wu, X. *Studies on blended cement with a large amount of fly ash*, Cement Concrete Res, 2002, **32**(79): 1153-1159.

[7] Ahmaruzzaman, A. M. *Review on the utilization of fly ash*, Progress in Energy and Combustion Science, 2009, pp. 1-37. (in press).

[8] Neville, A. M. *Properties of Concrete*, 4th and Final ed., 1996, Harlow, England: Longman.

[9] Ganjian, E and Pouya H.S. *The effect of Persian Gulf tidal zone exposure on durability of mixes containing silica fume and blast furnace slag*, Constr. Build Mater, 2009, **23**: 644-652.

[10] Subasi, S. *The Effects of Using Fly Ash on High Strength Lightweight Concrete Produced with Expanded Clay Aggregate*, Scientific Research and Essays, 2009, 4(4): 275-288.

[11] Yildiz, S., Balaydin, I. and Ulucan, Z. *The Effect of Rice Husk Ash on Concrete Strength (in Turkish)*, Sci. Eng. J. Fırat Univ., 2007, **19**(1): 85-91.

[12] Kaid, N., Cyr, M., Julien, S. and Khel, H. *Durability of concrete containing a natural pozzolan by a performance-based approach*, Constr. Build Mater, 2009, **23**: 3457-3467.

[13] ASTM C 618-8. *Standard specifications for fly ash and raw or calcined natural pozzolan for use as mineral admixture in Portland cement concrete*, ASTM. Philadelphia, 1985, USA.

[14] Aruntas, H.Y. *The potential of fly ash usage in construction sector*, J. Fac. Eng. Arch. Gazi Univ., 2006, **21**(1): 193-203. (in Turkish).

[15] Neville, A.M. *Properties of concrete*, Pearson Education limited, 2006, England.

[16] Mazloom, M., Ramezanianpour, A. A. and Brooks, J. J. *Effect of silica fume on mechanical properties of high-strength concrete*, Cement Concrete Compos, 2004, **26**: 347-357.

[17] Sanchez, F. and Ince, C. *Microstructure and macroscopic properties of hybrid carbon*
nano.ber/silica fume cement composites, Compos Sci. Technol, 2009, **69**: 1310-1318.
[18] Jo, B.W., Kim, C. H., Tae, G. and Park, J. B. *Characteristics of cement mortar with nano-*
SiO2 particles, Constr. Build Mater, 2007, **21**: 1351-1355.
[19] Qing, Y., Zenan, Z., Deyu, K. and Rongshen, C. *Influence of nano-SiO2 addition on*
properties of hardened cement paste as compared with silica fume, Constr. Build Mater,
2007, **21**: 539-545.
[20] Song, H. W., Pack, S.W., Nam, S. H., Jong, J. C. and Saraswathy, V. *Estimation of the*
permeability of silica fume cement concrete, Constr. Build Mater, 2010, **24**: 315-321.
Norsuzailina Mohamed Sutan et al. Concrete Research Letters Vol. 2 (4) – December 2011 335
[21] Yildiz, K. *The performance of silica fume admixtured concrete under the effect of ammonium*
sulfate (in Turkish), E-J. New World Sci. Acad Technol. Appl. Sci., 2008, **3**(2): 1-9.

Appendix : A

Figure A1 :- collection and weight of materials

Figure A2 :- Mold Preparation for Casting

Figure A3 :- Material preparation for casting

Figure A4:- Sieve analysis

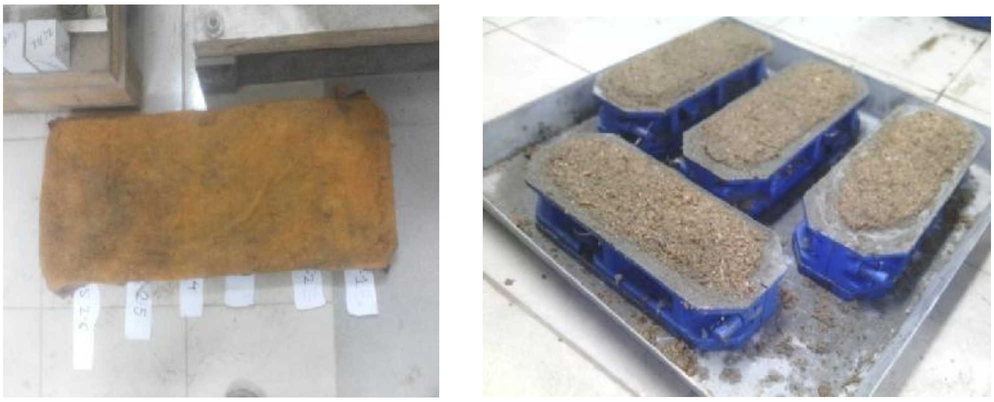


Figure A5 :- After casting, wet sand and wet cloth has been placed above sample to prevent moisture loss.

Figure A6 :- Demolded Sample

Figure A7 :- Sample crushing by UTM machine

Figure A8 :- Placing sample into crushing machine

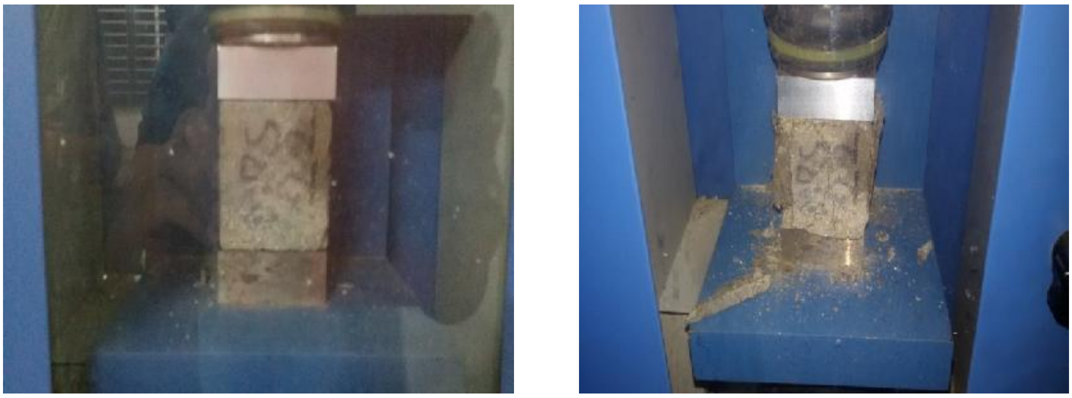
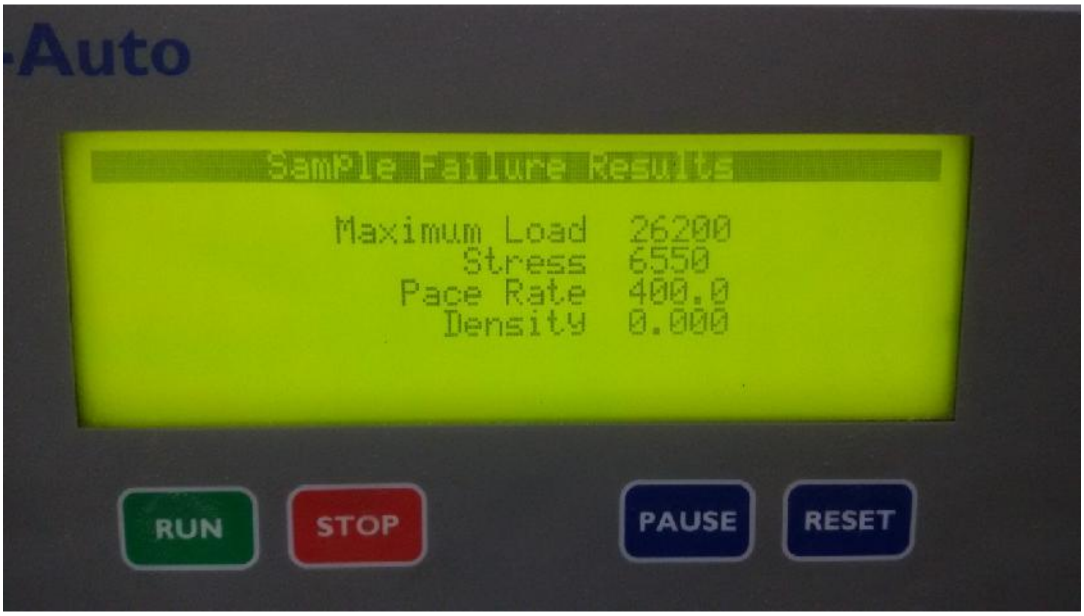


Figure A9 :- Sample Crushing



```
Sample Failure Results

Maximum Load   26200
      Stress   6550
   Pace Rate   400.0
     Density   0.000
```

Figure A10 :- Reading showing on crushing machine display

Figure A11 :- Crushed Sample