# QUALITY ASSESSMENT OF REPRESENTATIVE CEMENT BRANDS OF BANGLADESH

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## ABSTRACT

The increased demand of Bangladeshi cement in construction industry has gained attention of researchers, engineers and practitioners to understand the quality of cements. A number of industries produce cement not only to meet the local demand but also export cement abroad.

The research aims to investigate the physical qualities of cements of different brands of Bangladesh using experimental investigations. The physical properties of cement include normal consistency, initial and final setting time, compressive strength of cement mortars, compressive strength of cylindrical concrete, density, specific gravity and fineness of cement. Standard tests were performed on cements manufactured by ten different industries of Bangladesh. A total 300 tests samples on CEM II/B-M type representative cement samples were prepared to conduct tests on those physical parameters as per ASTM specifications.

The experimental results obtained from this study were also analyzed to investigate the statistical parameters. The results are compared with the ASTM guideline values and previous available study. In addition, correlations are also developed to find relationships between compressive strength of concrete and their age of curing. The influence of initial and final setting times on concrete strength are also investigated. The experimental result shows that almost all the samples meet the ASTM requirement that ultimately proves the good quality of Bangladeshi Cements. Moreover, the results are compared with an existing study for some cases. The comparison reveals that the quality of Bangladeshi cements has improved in last decade quite significantly in terms of mechanical strength of concrete. The relationship between mortar strength and concrete strength from the same batch of cement are also investigated.

In addition, Regression analyses are conducted using the tested results. The regression relationships among 28-days compressive strength of cement mortar and 3-days and 7-days compressive strength of cement mortar, the following relationships are obtained as follow $f'_{c-28D} = 2.10 * f'_{c-3D}$ and $f'_{c-28D} = 1.49 * f'_{c-7D}$ respectively. The coefficients of determination of the relationships, $R^2$ are 0.956 and 0.952 respectively. The regression relationships among 28-days compressive strength of cement cylindrical concrete specimens and 7-days and 14-days compressive strength of cylindrical concrete specimens are obtained as follow $f'_{c-28D} = 2.12 * f'_{c-7D}$ and $f'_{c-28D} = 1.71 * f'_{c-14D}$ respectively. The coefficients of determination of the relationships, $R^2$ are 0.99 and 0.976 respectively. The results obtained from this study is expected to provide clear understanding on the physical properties of Bangladeshi cement qualities and their applicability as ingredient of concrete.

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## LIST OF SYMBOLS

| | |
|---|---|
| Density of cement | $\rho$ |
| Mass of the cement | m |
| Displaced volume v | |
| Weight of cement | W |
| Specific surface of the test sample | S |
| Specific surface of the standard sample used in calibration of the apparatus | $S_s$ |
| Measured time interval of manometer drop for test sample | T |
| Measured time interval of manometer drop for standard sample used in calibration of the apparatus | $T_s$ |
| Viscosity of air at the temperature of test of the test sample | $\eta$ |
| Viscosity of air at the temperature of test of the standard sample used in calibration of the apparatus | $\eta_s$ |
| Porosity of prepared bed of test sample | $\epsilon$ |
| Porosity of prepared bed of standard sample used in calibration of apparatus | $\epsilon\epsilon_s$ |
| Density of standard sample used in calibration of apparatus | $\rho_s$ |
| Constant specifically appropriate for the test sample | b |
| Appropriate constant for the standard sample | $b_s$ |
| Y-intercept | a |
| Slope | b |
| Coefficient of determination | $R^2$ |

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# CHAPTER - 1

# INTRODUCTION

## 1.1 General Remarks

Cement is a major ingredient of concrete structures and it plays a key role in the construction industry. The extent of use of cement depends on the rate of urbanization and the amount of development projects undertaken **[1]**. Cement acts as a binding material which forms a matrix in the presence of water and fine aggregates which holds the coarse aggregates together. Hence, it becomes necessary to test cement to know its physical, chemical and mechanical properties for concrete construction works. Due to a huge demand of cement in concrete structures, enormous growth of the cement industry can be noticed in the last two decades. Consequently, concrete strength is a very important factor in construction **[2-4]**. So, it is required to investigate the quality of cement in Bangladesh. The quality assessment of some cement brands of Bangladesh has been described in the following chapters.

### 1.1.1 History of Cement

Throughout history, cementing materials have played a vital role and were used widely in the ancient world. The Egyptians used calcined gypsum as cement and the Greeks and Romans used lime made by heating limestone and added sand to make mortar with coarser stones for concrete. The Romans found that cement could be made which set under water and this was used for the construction of harbors. This cement was made by adding crushed volcanic ash to lime and was later called a "pozzolanic" cement named after the village of Pozzuoli near Vesuvius. In places where volcanic ash was scarce such as Britain, crushed brick or tile was used instead. The Romans were therefore probably the first to manipulate systematically the properties of cementations materials for specific applications and situations **[5]**.

### 1.1.2 Evolution of Cement

The Renaissance and age of explanation brought new ways of thinking which led to the industrial revolution. In eighteenth century, Britain, the interests of industry and empire coincided with the need to build lighthouses on exposed rocks to prevent shipping losses. The constant losses of merchant ships and warships drove cement technology forwards. Smeaton, building the third Eddy stone lighthouse (1759) off the coast of Cornwall in Southwestern England found that a mix of lime, clay and crushed slag from iron making produced a mortar which hardened under water. Joseph Aspdin took out a patent in 1824 for "Portland Cement", a material he produced by firing finely ground clay and limestone until the limestone was calcined. He called it Portland cement because the concrete made from it looked like Portland stone, a widely used building stone in England. While history usually regards Aspdin as the inventor of Portland cement, Aspdin's cement was not produced at a high-enough temperature to be the real forerunner of modern Portland cement. A few years later, in 1845, Isaac Johnson made the first modern Portland cement by firing a mixture of chalk and clay at much higher temperatures, similar to those used today. At these temperatures (1400C-1500C), clinkering occurs and minerals form which are very reactive and more strongly cementitious. While Johnson used the same materials to make Portland cement as we use now, three important developments in the manufacturing process lead to modern Portland cement:

i) Development of rotary kilns

ii) Addition of gypsum to control setting

iii) Use of ball mills to grind clinker and raw materials

The time period during which concrete was first invented depends on how one interprets the term “concrete.” Ancient materials were crude cements made by crushing and burning gypsum or limestone. Lime also refers to crushed, burned limestone. When sand and water were added to these cements, they became mortar which was a plaster-like material used to adhere stones to each other.  Over thousands of years, these materials were improved upon combined with other materials and ultimately morphed into modern concrete. Today’s concrete is made using Portland cement, coarse and fine aggregates of stone, sand and water.  Admixtures are chemicals added to the concrete mix to control its setting properties. The precursor to concrete was invented in about 1300 BC when Middle Eastern builders found that when they coated the outsides of their pounded clay fortresses and home walls with a thin, damp coating of burned limestone, it reacted chemically with gases in the air to form a hard, protective surface. This wasn’t concrete but it was the beginning of the development of cement. Early cementicious composite materials typically included mortar-crushed, burned limestone, sand and water which was used for building with stone as opposed to casting the material in a mold which is essentially how modern concrete is used with the mold being the concrete forms. As one of the key constituents of modern concrete, cement has been around for a long time. About 12 million years ago in what is now Israel, natural deposits were formed by reactions between limestone and oil shale that were produced by spontaneous combustion.

In 1824, an Englishman named Joseph Aspdin invented Portland cement by burning finely ground chalk and clay in a kiln until the carbon dioxide was removed.

It was named “Portland” cement because it resembled the high-quality building stones found in Portland, England. It’s widely believed that Aspdin was the first to heat alumina and silica materials to the point of vitrification, resulting in fusion. During vitrification, materials become glass-like. Aspdin refined his method by carefully proportioning limestone and clay, pulverizing them and then burning the mixture into clinker which was then ground into finished cement **[5, 6]**.

### 1.1.3 Portland Cement

Ancient Romans were probably the first to use concrete. A word of Latin origin based on hydraulic cement that is a material which hardens under water. This property and the related property of not undergoing chemical change by water in later life are most important and have contributed to the widespread use of concrete as a building material. Roman cement fell into disuse and it was only in 1824 that the modern cement known as Portland cement was patented by Joseph Aspdin, a Leeds builder. Portland cement is the name given to a cement obtained by intimately mixing together calcareous and argillaceous or other silica alumina and iron oxide- bearing materials, burning them at a clinkering temperature and grinding the resulting clinker **[7-14]**.

### 1.1.4 Manufacturing Process of Portland cement

From the definition of Portland cement given above, it can be seen that it is made primarily from a combination of a calcareous material such as limestone or chalk and silica and alumina found as clay or shale. The process of manufacture consists essentially of grinding the raw materials into a very fine powder, mixing them intimately in predetermined proportions and burning in a large rotary kiln at a temperature of about 1400 $^{o}$C (2550 $^{o}$F) when the material sinters and partially fuses into clinker. The clinker is cooled and ground to a fine powder, with some gypsum added and the resulting product is the commercial Portland cement used throughout the world.

The mixing and grinding of the raw materials can be done either in water or in a dry condition; hence, the names wet and dry process. The mixer is fed into a rotary kiln, sometimes (in the wet process) as large as 7 m (23 ft) in diameter and 230 m (750 ft) long. The kiln is slightly inclined. The mixer is fed at the upper end while pulverized coal (or other source of heat) is blown in by an air blast at the lower end of the kiln, where the temperature may reach about 1500 $^{0}$C (2750 $^{0}$F). The amount of coal required to manufacture one tonne (2200 lb) of cement between 100 kg (220 lb) and about 350 kg (770 lb), depending on the process used.

As the mixture of raw materials moves down the kiln, it encounters a progressively higher temperature so that various chemical changes take place along the kiln. First, any water is driven off and $CO_2$ is liberated from the calcium carbonate. Further on, the dry material undergoes a series of chemical reaction until, finally in the hottest part of the kiln, some 20 to 30 percent of material becomes liquid and lime, silica and alumina recombine. The mass then fuses into balls, 3 to 25 mm in diameter known as clinker. Afterwards, the clinker drops into coolers which provide means for an exchange of heat with the air subsequently used for the combustion of the pulverized coal. The cool clinker, which is very hard, is inter-ground with gypsum in order to prevent flash-setting of the cement **[7-14]**.

### 1.1.5 Basic Chemistry of Cement

The raw materials used in the manufacturing of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products and apart from a small residue of un-combined lime which has not sufficient time to react, a state of chemical equilibrium is reached. However, equilibrium is not maintained during cooling and the rate of cooling will affect the degree of crystallization and the amount of amorphous material present in the cooled clinker. The properties of this amorphous material, known as glass, differ considerably from those of crystalline compounds of a nominally similar chemical composition. Another complication arises from the interaction of the liquid part of the clinker with the crystalline compounds already present. Cement can be considered as being in frozen equilibrium i.e. the cooled products are assumed to reproduce the equilibrium existing at the clinkering temperature. This assumption is in fact made in the calculation of the compound composition of commercial cements: the ‘potential’ composition is calculated from the measured quantities of oxides present in the clinker as if full crystallization of equilibrium products had taken place **[7-14]**.

Four compounds are regarded as the major constituents of cement:

Table 1.1: Major constituents of cement **[7]**.

| Sl. No. | Name of compound | Oxide composition | Abbreviation |
|---|---|---|---|
| 1 | Tricalcium silicate (Alite) | $3CaO.SiO_2$ | $C_3S$ |
| 2 | Dicalcium silicate (Belite) | $2CaO.SiO_2$ | $C_2S$ |
| 3 | Tricalcium aluminate (Cellite-II) | $3CaO.Al_2O_3$ | $C_3A$ |
| 4 | Tetracalcium aluminoferrite (Cellite-I) | $4CaO.Al_2O_3.Fe_2O_3$ | $C_4AF$ |

Table 1.2: Composition of limits of Portland cement **[7]**.

| Sl. No. | Oxide | Content (%) |
|---|---|---|
| 1 | CaO | 60-67 |
| 2 | $SiO_2$ | 17-25 |
| 3 | $Al_2O_3$ | 3-8 |
| 4 | $Fe_2O_3$ | 0.50-6 |
| 5 | MgO | 0.10-4 |
| 6 | Alkalis | 0.20-1.3 |
| 7 | $SO_3$ | 1-3 |

### 1.1.6 Cement Industry in Bangladesh

In Bangladesh, relative rapid growth of cement industry has been observed since mid-80s. At present, the cement industry of the country is the 40th largest market in the world. Primarily five types of Portland cement are used worldwide. However, in Bangladesh two types of cement are produced known as CEM I and CEM II. CEM I is Ordinary Portland cement (OPC) with no SCM (Supplementary Siliceous Materials such as fly ash, slag, silica fume etc.). CEM II is the Portland Composite Cement (PCC) where SCM or pozzolana is added by replacing the clinker. In areas of durability problem such as sulphate or chloride attack, PCC performs better. Before 2003, mainly OPC was used in Bangladesh. From 2003, production of Portland Composite Cement (PCC) has started in the country following the European Standard Methods (ESM). PCC gives comparable strength and durability like OPC. As a result, PCC is gaining popularity worldwide due to its environmental significance **[15]**. At present Lafarge Holcim cement company is producing PLC (Portland Limestone Cement) type cement. PLC is a slightly modified version of portland cement that improves both the environmental footprint and potentially the basic performances in concrete. It can be made at any portland cement manufacturing plant. While ordinary Portland cement (OPC) may contain up to 5% limestone, PLC contains between 5% and 15% limestone.

Clinker plays the most vital role for ensuring the strength and quality of cement. Most of the clinker used for cement production in Bangladesh is imported. Only two manufacturers produce clinker at their own plant. One is Chhatak Cement Factory Ltd a government owned company with a limited production capacity. Another one is Lafarge Surma Cement Ltd, which is situated at Chhatak, Sunamganj and produces approximate 10% of total clinker required for Bangladesh **[15]**.

Currently the industry is experiencing overcapacity of cement production. In a recently surveyed report by Cement Manufacturer's Association, it has been found that there is production capacity of 40 million tons, whereas actual production is hovering around 32 million tons. On an average the utilization rate of cement manufacturing companies is currently around 75-80%. There are currently 34 companies who are operating as cement producer. Present installed capacity of the industry is 40 million MT. Presently, the actual production of all plants in Bangladesh is roughly 32 million MT which means that the sector is now utilizing roughly 80% of the total industry capacity. At present the demand side of the market is mainly dominated by Government's infrastructure development projects, industrial constructions and real estate companies and independent home builders. Export revenue from Cement has dropped significantly in recent period. In the FY2015-16, the export of cement from Bangladesh amounted to USD 1.71 million (BDT 133.6 million) which was USD 3.94 million (BDT 307.8 million) in FY 2014-15, representing 43.4% plunge in export sales. Bangladesh started exporting cement from 2003. M.I. Cement Factory Limited was the pioneer in cement export from Bangladesh. Cement export data presents that Crown Cement (a brand of M.I. Cement) accounts for 37% of the total export volume in cement **[1]**. Cement industry in Bangladesh is currently in a growing phase as the consumption of cement has steadily been rising. Till now, strength is the main focus of quality related issues of cement in the country and overall quality of cement production is quite satisfactory. However, in order to ensure overall sustainability, other durability issues dependent on cement properties need to be considered **[15]**.

### 1.2 Background and Present state of the Problem

The development of cement industry in Bangladesh dates back to the early-fifties. Till 1990 about 95% of the country's demand for cement had been met through import. Some enthusiastic entrepreneurs ventured into setting up cement plants during 1997 to 2000 which opened a new era in this sector. Prior to inception, Bangladesh used to import cement from global market. As new manufactures entered into the market with no participants, they tapped into the already existing huge demand for cement. The dependency on import lowered in the following years. Currently local producers and multinational companies have engaged in cement production to fulfill the local demand.

According to International Mining and Resources Conference group, the global market rose to volume of around 5.0 billion tons in 2016 which was around 3.7 billion tons in the year 2012. Chinese market has continued to be the biggest driver of growth alongside countries from North America as USA has continued to recover from recessionary conditions that began in 2007. In the upcoming years India is expected to garner the fastest growth in terms of demand for cement generating 8.0% growth rate per year in the next five years. Although the growth in the demand of cement has been increasing in Bangladesh, it is far below than that of many developing countries. So, there is a broader scope of growth for cement sector of Bangladesh. The ongoing construction projects are contributing towards the growing demand of cement but delaying in the implementation of projects are curtailing the full potential and speed of the consumption growth of cement. Bangladesh is one of the lowest consumers of cement products in the world **[1]**.

Table 1.3: Per Capita Cement Consumption (Kg) in 2016 **[1]**.

| Sl No. | Name of Country | Consumption, Kg |
|---|---|---|
| 1 | China | 1700 |
| 2 | Malaysia | 320 |
| 3 | Srilanka | 310 |
| 4 | India | 220 |
| 5 | Pakistan | 170 |
| 6 | Bangladesh | 120 |
| 7 | Global | 500 |

Table 1.4: Per Capita Cement Consumption (Kg) in 2018 **[16]**.

| Sl No. | Name of Country | Consumption, Kg |
|---|---|---|
| 1 | China | 1700 |
| 2 | South Korea | 1250 |
| 3 | Malaysiya | 800 |
| 4 | Thailand | 500 |
| 5 | India | 312 |
| 6 | Myanmar | 270 |
| 7 | Bangladesh | 187 |
| 8 | World Average | 563 |

In 2016, average per capita cement consumption in the world is 500 kg while that of Bangladesh is only 120 kg **[1, 4]**. In 2018 average per capita cement consumption in the world is 563 kg while that of Bangladesh is only 187 kg. However, per capita cement consumption in Bangladesh witnessed lucrative growth over the last few years **[16]**. Concrete construction works in Bangladesh is rapidly increasing due to the necessity of development of significant number of infrastructures as well as booming of real estate business and MRT LINES (DMTCL Project) not only in the capital city Dhaka but also in other major cities, such as Chittagong, Sylhet, Cox-Bazar, Comilla, etc. Due to a huge demand of cement in concrete structures, more than 34 national and international cement companies are producing cement in Bangladesh and supplying it to the market with different brand names **[2-4]**. In Bangladesh, the per capita per year cement consumption was 22 kg in 1999, but it is increased to 187 kg in 2018 **[16]**. Therefore, it is necessary to take steps for ensuring sustainable construction works so that the structures which are constructed today will be durable for a long service life and thereby will reduce the demand of cement for making concrete in future. Several studies have been carried out on cement testing in various aspects by different researches. But very few studies have been carried out on strength of concrete due to quality control in Bangladesh. Based on this background, a research project has been taken to figure out the performance of different brand cement so that sustainability in construction work can be ensured **[17-21]**.

### 1.3 Objectives

The main objectives of this project work are

(i) To study physical properties of representative cement brands of Bangladesh.

(ii) To conduct experimental investigations on representative cements as per ASTM guideline and hence determine their comparative performance in concrete for last two decades.

Firstly, the main outcome of this study is to identify the ingredients of representative cement brands of Bangladesh and hence to compare their deviation from the standard range. Secondly, the performance of different cements is investigated in concrete construction in terms of setting time, consistency and mechanical strength enhancement. Finally, regression analyses are also performed with the experimental results to understand concrete strength at different ages and hence predict relationship between concrete of different ages and their dependence on mechanical strength.

### 1.4 Methodology

This research has been conducted experimentally on representative cement brands to investigate the physical properties of cements as per ASTM standard. In order to investigate the physical properties of cement, specific gravity and fineness tests have been conducted. The chemical composition of the cement is recorded from the cement bags. Additionally, normal consistency, initial and final setting times of different cement types are also examined as per ASTM guideline. Samples are also prepared to conduct experimental investigations for cement mortar test, compressive strength test by cement concrete cylinder.

It is important to highlight that all tests are conducted as per ASTM standard instead of BDS ISO. Since, Bangladeshi cement is widely exported all over the world, ASTM standard are considered to be more acceptable as compared to the BDS ISO. Moreover, cements are produced in Bangladesh following BDS ISO but Bangladesh National Building Code (BNBC) refers to ASTM for concrete design. Therefore, this research has been conducted with a view to employing its outcome globally besides maintaining local requirements. In addition, compressive strength at 3 days, 7 days, 14 days, and 28 days have been tested following ASTM standards to obtain the samples age influence on the strength of concrete. Based on the experimental results, a regression analysis has been developed to predict the concrete strength at different ages.

### 1.5 Layout of Project Paper

The report is organized into five chapters. The general background, objective of the study and methodology of the work are presented briefly in Chapter 1 to provide fundamental idea of the work being done under the study. Chapter 2 deals with the literature review which includes previous similar studies. In view of the Global and regional demand, production, utilization, major manufacturers, market demand or segmentation and export of Bangladeshi cement are described in Chapter 2. In Chapter 3, all experimental procedures test set-up, testing plan and finally test matrix are presented in detail. Chapter 4 is composed of all experimental results, graphical presentation and discussion of the research work. The chapter also includes the regression analyses, their parameter and also the prediction of concrete strength at different ages. The comparison of outcomes with previous studies are also presented in Chapter 4. Chapter 5 draws conclusions by summarizing the outcome of the research and new directions for further research and developments.

# CHAPTER - 2

# LITERATURE REVIEW

## 2.1 Introduction

Due to a massive demand of cement in concrete structures, huge growth of the cement industry is noticed in last two decades. Although the cement demand in both local and international market is quite high, quality of cement still an issue mainly because not much research work has been conducted on Bangladeshi cements **[4]**. Concrete strength is a very important factor in the construction of concrete structure and cement plays a major role there. This chapter includes the literature of local cement quality assessments, global and regional demand, production, utilization, major manufacturers, market demand or segmentation, pricing and export of cement.

## 2.2 Experimental Study

A number studies have been carried out on cement testing in various aspects by different researches. But very few studies have been carried out on strength of concrete due to quality control in Bangladesh.  Present study will be carried out for a comparative study on strength of concrete at various ages in Bangladesh will be followed by ASTM codes. Very limited of studies have been done on this aspect. It is helpful to an engineer to know the concrete strength in difference ages. Various researches carried out on concrete strength are given below:

Kozul and Darwin **[26]** published a research paper on effects of aggregate type, size and content on concrete strength and fracture energy. The objective of this study was the effects of aggregate type, size and content on the behavior of normal and high-strength concrete and the relationships between compressive strength, flexural strength and fracture energy.

Wen and Chung **[27]** published a research report on effect of stress on the electric polarization in cement. In this study, Compressive stress was found to diminish the extent of electric polarization in the transverse direction in cement pastes with and without carbon fibers. In addition, the stress decreased the time for polarization to essentially reach completion. The extent of polarization was much smaller when carbon fibers were present. It was smaller for carbon fiber cement paste containing silica fume than that containing latex.

Monzon **[28]** carried out a research on maturity of concrete-strength development. The maturity method was investigated in this thesis to determine (a) how well field cast concrete strengths can be predicted from generated strength-maturity curves and (b) what effects different wet mat curing durations have on strength development and overall strength. The objective of this thesis was to compare the compressive strengths of in-situ four-inch diameter cores taken from bridge decks with predicted strengths based on (a) strength-maturity curves developed from six-inch diameter field-cast cylinders and (b) strength-maturity curves developed from six-inch diameter lab-cast cylinders.

Abdullahi **[29]** published a journal on characteristics of wood ASH/OPC concrete. The study was presented the behavior of wood ash / OPC concrete. Chemical analysis of wood ash, bulk density, sieve analysis and specific gravity of wood ash and aggregates, consistency, setting time and slump test of the fresh paste were conducted to determine the suitability of the materials for concrete making. Test result indicated that the wood ash was slightly pozzolanic, water demand was increased as the ash content increased and the setting time of the paste increased as the ash content increased. Compressive strength of wood ash/OPC concrete it increased with age at curing with optimum replacement of cement by wood ash of 20%.

Asik **[30]** carried out a research on structural lightweight concrete with natural perlite aggregate and perlite powder. The study was to investigate the performance of structural lightweight aggregate concrete with the use of natural perlite aggregate and to obtain a more economical structural lightweight aggregate concrete mixture with the use of perlite powder as a cement replacement. Two groups of concrete mixtures were produced with different cement contents and water/cementitious-materials ratio (w/cm). Superplasticizer was used in all mixtures to obtain the required slump and workability. For the mixtures produced, properties of fresh concrete such as: slump, density, air-content and setting time were determined. Also, compressive strength, tensile strength and modulus of elasticity of hardened concrete and as a durability performance, drying shrinkage and chloride penetration of hardened concrete were determined.

Moreover, the effect of perlite powder on the properties of fresh and hardened concrete was investigated.

Labarca et al. **[31]** carried out a research on effects of ground granulated blast furnace slag in portland cement concrete. The objective of this study was to determine variations in performance for grade 120 slag cement concrete using a range of materials common to Wisconsin highway pavement construction. The research plan was consisted to assess the variability of slag cement over a period of one year, assess the strength gain (both compressive and split-tensile strengths) and air void development under various conditions and assess the deicer scaling resistance under various conditions.

Barnett et al. **[32]** published a journal on fast-track construction with slag cement concrete**.** The aims of the project were (a) quantifying the enhancement in strength that may be expected due to high early-age temperatures in structural elements. The initial part of the investigation looked at the strength development of concretes with low, medium and high strengths and with up to 70% of the total binder being slag cement under adiabatic conditions. (b) The applicability of maturity functions, determined empirically from work on portland-cement concretes for slag cement concretes. Relationships between strength and maturity were determined using data from cubes cured at 20 °C (68 °F). These relationships were then used together with the adiabatic temperature history to predict the strength development under adiabatic curing conditions.

Swamy **[33]** published a paper on sustainable concrete for the 21st century concept of strength through durability. The objective of this paper was to show that the current emphasis on high strength and very high strength and the design philosophy of Durability through Strength for concrete materials and concrete structures is fundamentally flawed. To avoid the lack of durable performance of concrete in real life, the concrete materials must be manufactured for durability and not for strength. This study showed that the concept of Strength through Durability can be achieved through careful design of the cement matrix and its microstructure.

Samuel and Anthony **[34]** carried out a research on comparing the compressive strength of concrete utilizing natural pozzolana as a partial replacement of ordinary portland cement in concrete production. The aim of the study was to compare the strength of concrete using a mixture of pozzolana and Ordinary Portland Cement (OPC) as a binder to that of OPC only in concrete production. The objective of this study was to investigate the performance of locally available natural pozzolanic material in the republic of Ghana and to investigate the influence of the pozzolan on the properties of fresh concrete and compressive strength development.

Allena and Newtson **[35]** focused a paper on ultra-high strength concrete mixtures using local materials. This paper presented the development of ultra-high strength concrete

(UHSC) using local materials. UHSC mixture proportions were developed using local materials so that UHSC may be made more affordable to a wider variety of applications. Specifically, local sand with a top size of 0.0236 in. (600 μm), and locally available Type I/II cement and silica fume were used in this research. Each of these material selections was seen as an improvement in sustainability for UHSC. Two mixtures (one with and one without fibers) were recommended as the UHSC mixtures. The greatest compressive strengths obtained in this study were 24,010 psi (165.6 MPa) for UHSC with steel fibers and 23,480 psi (161.9 MPa) for UHSC without fibers. Producing this innovative material with local materials reduces the cost of the material, improves sustainability, and produces mechanical performance similar to prepackaged, commercially available products.

Karim et a1. **[36]** published a journal on strength development of mortar and concrete containing fly ash. In this paper, a critical review on the strength development of concrete as influenced by the use of Fly Ash (FA) as a supplement of cement (OPC) in concrete was presented on the basis of available information in the published literatures of utilization of FA in blended cement and concrete. The compressive strength of mortar and concrete as varied by the percent replacement and fineness of FA was discussed here. Physical and chemical properties, pozzolanic activity, normal consistency and setting time, strength activity index, advantages and disadvantages of using FA in concrete was also pointed out. Main objective of this study was proper consumption of FA as pozzolanic material in concrete that would be a useful step for the production of cost effective and more durable concrete. Besides, utilization of FA in cement and concrete could reduce negative environmental effect and also would be the appropriate solution for the disposal of this waste.

Hasan and Kabir **[37]** presented a paper on prediction of compressive strength of concrete from early age test result. Objective of all studies that have been carried out was to make the concrete strength predictable and increase the efficiency of the prediction. In this paper, an attempt was made to develop a relation between concrete strength and its age.

Sanish and Santhanam **[38]** presented a paper on characterization of strength development of concrete using ultrasonic method. Ultrasonic non-destructive testing was applied in numerous ways to assess the condition of concrete in structures. This paper was compacted with application of ultrasonic methods on early age concrete to track the strength development in concrete. In this investigation, ultrasonic through-transmission signals were analyzed for their amplitude and pulse velocity. When concrete changes from the fresh, fluid state to hardened, solid state, changes in the amplitude of the ultrasonic signal passed through the concrete specimen can be observed. Amplitude values are an indication of total energy passing through the test specimen, from which one can derive energy curves. As the concrete hardens, the amount of energy transmitted through concrete increases and this change is related to strength development in concrete.

Amudhavalli and Mathew **[39]** published a journal on effect of silica fume on strength and durability parameters of concrete. Large scale production of cement is causing environmental problems on one hand and depletion of natural resources on other hand. This threat to ecology was led to researchers to use industrial by products as supplementary cementations material in making concrete. The main parameter investigated in this study was M35 grade concrete with partial replacement of cement by silica fume by 0%, 5%, 10%, 15% and 20%. This paper was presented a detailed experimental study on compressive strength, split tensile strength, flexural strength at age of 7 and 28 days. Durability study on acid attack was also studied and percentage of weight loss was compared with normal concrete. Test results indicated that use of silica fume in concrete had improved the performance of concrete in strength as well as in durability aspect.

Alsadey **[40]** presented a paper on effects of super plasticizing and retarding admixtures on properties of concrete. According to this paper, the adverse effects of elevated temperatures on the properties of the fresh concrete include increased water demand, shorter setting time and increased slump loss. Superplasticizers (SP) and retarders are important to enhance the workability and setting time of concrete under hot weather, hence, an experimental investigation was conducted to determine the optimum dosage for the admixtures and to study the effect of over dosage of the mentioned admixtures. Concrete mixes with SP and retarder dosages of 600, 1200, 1800, and 2500 ml/100 kg of cement were prepared, together with control mix (water/cement ratio were 0.50). After casting, normal curing was carried out on the concrete samples. Properties such as compressive strength, was determined, besides determining the workability of the fresh concrete. Over dosage of SP or retarder were found to deteriorate the properties of concrete with indication of lower compressive strength. However, if the dosage levels are lower than the optimum dosage, increase in admixture dosage might help to enhance the concrete characteristics.

Supit and Shaikh **[41]** published a journal on effect of Nano-$CaCO_3$ on compressive strength development of high volume fly ash mortars and concretes. This paper presented the experimental results on the effect of nano-CaCO3 on compressive strength development of mortars and concretes containing high volume fly ash (HVFA). The effect of various nano-$CaCO_3$ contents such as 1, 2, 3 and 4% (wt.%) as partial replacement of cement on the compressive strength of mortars were evaluated in the paper. The nano-$CaCO_3$ content which exhibited the highest compressive strength above was used in high volume fly ash mortars and concretes containing 40% and 60% class F fly ash. The results were shown that among four different nano-CaCO3 contents, the addition of 1% nano-CaCO3 increased the compressive strength of mortars and concretes. The addition of 1% nano-CaCO3 also increased the early age and 28 day compressive strengths of HVFA mortars and concretes.

Bamigboye et al. **[42]** published a research paper on assessment of compressive strength of concrete produced from different brands of portland cement. The objective of this research was to determine the cement brands that have the highest compressive strength to enhance the quality and durability of the structures being built in the country. Different brands of Portland cement were used to produce concrete varying with 1:2:4 and 1:3:6 mix ratio respectively with a curing date of 3, 7, 14, 21, and 28 days respectively. No additive was used in any of the mix. The tests were carried out include slump test at its fresh state while compressive strength was carried out for the hardened concrete, also the vicat test was carried out on the cement brands to determine the setting time.

Patel et al. **[43]** published a paper on review on partial replacement of cement in concrete. This study includes, today construction cost is very high with using conventional materials due to unavailability of natural materials. This problem can be solved by total replacement of concrete with different material which is not convenient in terms of required properties. Due to this limitation of unavailability of material which plays the vital role of concrete have only choice of partial replacement of concrete ingredients by waste materials. Over 3.3 billion tons of cement was consumed globally in 2010 based on survey of world coal association and also cement production emits CO2 in to the atmosphere which is harmful to the nature. If can partially replace the cement with the material with desirable properties, then we can save natural material and reduce emission of CO2 in to the atmosphere. This industrial waste dumping to the nearest site which spoils the land and atmosphere as well as it also affects aesthetics of urban environment so use of this waste material in concrete is cost effective as well as environment friendly way to disposal of waste. The primary objective of this study is to select the waste material which gives desirable properties with concrete. This study includes previous investigation done on the mechanical and chemical properties of concrete produced using partial replacement of cement by waste materials.

Heniegal et al. **[44]** published an international journal on physical and mechanical properties of concrete incorporating industrial and agricultural textile wastes. The objective of this study was to reduce the impact on the environment, industrial and agricultural waste products such as carpet waste, sisal and flax have been added to the concrete. Usage of these materials in concrete does not only improve the strength of concrete but also leads to the proper disposal of these materials that leads to reduce the impact on environment. Fiber admixture can effectively improve the mechanical and physical properties of concrete.

Anitha et al. **[45] p**ublished an international journal on influence of admixtures on behavior of concrete. In this investigation on performance of concrete with GGBS and different PCE based water reducing admixture the tests on compressive strength and workability of the concrete with Ordinary Portland cement and Portland pozzolana cement with GGBS and admixture are carried out at different curing periods for M45 grade of concrete to conclude its behavior. Compressive strength at 1 day, 3 days, 7 days and 28 days of PCE based concrete is higher than these collected in the case of normal concrete, independent of the cement type and admixture.

Rumman et al. **[46]** focused a conference paper on comparison of CEM I and CEM II cement concretes in terms of water permeability. Bangladesh being a riverine country faces a challenge in case of water permeability of those structures. Impermeability is the main condition of durable concrete. Water ingress causes corrosion of reinforcement which can lead to weakening of structural member or even to failure. In this study water permeability test has been performed on concretes made with both Ordinary Portland Cement (CEM I) and Portland Composite Cement (CEM II) to observe the effect of water penetration on them. it was observed that CEM II cement concretes showed lower permeability than CEM I cement. Thus it can be concluded that CEM II concrete was found to perform better in the long run.

Jo et al. **[47]** published an international journal on strength and durability assessment of portland cement mortars formulated from hydrogen-rich water. This study was investigated the effects of hydrogen-rich water (HRW) on the strength and durability of Portland cement mortars. It was comparatively assessed the performances of HRW-based mortars (HWMs) with respect to cement mortars fabricated from control water (CWM). The results indicate that the use of HRW significantly improves the compressive, flexural, and splitting tensile strength of mortars at both the early and later ages of curing. This study focused the use of HRW in Portland cement mortars produces a more compact, dense, and durable microstructure with fewer voids due to a higher degree of hydration.

Miah et al. **[17]**, Mohammed **[18]**, Hasan et al. **[19]**, Rashid et al. **[20]** and Siddiqui et al. **[21]** carried out a research on investigation on factors related to sustainable development of concrete technology in Bangladesh. The objectives of their research work were the causes of deterioration of concrete structures, quality of cement brands, properties of concrete, recycling of demolished concrete as coarse aggregate for new construction, recycling of demolished concrete as fine aggregate for new construction.

Mohammed **[4]** carried out a research on Investigation of different cement brands commonly used in Bangladesh. The objective of the research work was common causes of deterioration of concrete structures in Bangladesh, common problems at construction sites that cause early deterioration of concrete structures in Bangladesh, mechanical properties of concrete made with different aggregates available in Bangladesh, investigation on different cement brands available in the market in Bangladesh, recycling of demolished concrete as coarse aggregate for new construction works and recycling of demolished concrete as fine aggregate for new construction works and making blocks.

EBL Securities Ltd. **[1, 16]** published a research on comprehensive review on Bangladesh cement industry. They focused global and regional demand of cement, production, utilization, export, major manufacturers, market demand or segmentation and pricing of cement.

According to Mohammed **[4]** a comparative study on quality assessment of cement, their physical properties and strength of concrete are described in this study. Due to conduct the research of Mohammed **[4]**, a total of 30 cement bags of different brands collected from various local dealers. After collection, each cement bag kept in an air-tight plastic bag to prevent unwanted hydration with the moisture present in air. Ingredients of cement printed on the collected cement bags were recorded. No further test conducted to re-check the composition of cement printed on the cement bags. Immediately after collection of the cement bags from the market, cement samples tested in the laboratory for normal consistency (ASTM C187), initial and final setting time (ASTM C191), compressive stregth (ASTM C109), fineness of cement (ASTM C184), bleeding (ASTM C 243) and bulk unit weight (ASTM C 128). For testing compressive stregth, instead of Ottawa sand, standard graded locally available sand used. Compressive stregth of cement mortar tested at the age of 3, 7, 14, and 28 days. Out of the thirty cement bags collected from the market, two samples fell in the group of CEM I (Sample No. 1 and 2), 15 samples fell in the group of CEM II/A-M (indicated as Sample No. 3 to 17), **9 samples fell in the group of CEM II/B-M (Sample No. 18 to 26)**, 3 samples fell in the group of CEM II/A-S (Sample No. 27 to 29) and one sample fell in the group of CEM II/A-L (Sample No. 30). Current study has been compared with the results of CEM II/B-M type cements.

Part researches are reviewed here elaborately and divided into several parts. According to EBL Securities Ltd. **[1, 16]** research report, present situation of Bangladesh cement industry is described mainly in this chapter. On the basis of huge demand of cement, a comparative study on strength of concrete at various ages in Bangladesh is highlighted in this research.

### 2.3 Development of Cement Industry in Bangladesh

The development of cement industry in Bangladesh dates back to the early-fifties. Till 1990 about 95% of the country's demand for cement had been met through import. Some enthusiastic entrepreneurs ventured into setting up cement plants during 1997 to 2000 which opened a new era in this sector. Prior to inception, Bangladesh used to import cement from global market. As new players entered into the market with no participants, they tapped into the already existing huge demand for cement. The dependency on import lowered in the following years. Currently local producers and multinational companies have engaged in cement production to fulfill the local demand. Fueled by the extensive growth of Chinese cement market and cement markets of developing countries, the global cement market has experienced a massive growth. According to IMARC group, the global market rose to volume of around 5.0 billion tons in 2016 which was around 3.7 billion tons in the year 2012.

Although the growth in the demand of cement has been increasing in Bangladesh, it is far below than that of many developing countries. So, there is a broader scope of growth for cement sector of Bangladesh. The ongoing construction projects are contributing towards the growing demand of cement but delaying in the implementation of projects are curtailing the full potential and speed of the consumption growth of cement. Bangladesh is one of the lowest consumers of cement products in the world **[1]**.

Table 2.1: Per Capita Cement Consumption (Kg) in 2016 **[1]**.

| **Sl No.** | **Name of Country** | **Consumption, Kg** |
|---|---|---|
| 1 | China | 1700 |
| 2 | Malaysia | 320 |
| 3 | Srilanka | 310 |
| 4 | India | 220 |
| 5 | Pakistan | 170 |
| 6 | Bangladesh | 120 |
| 7 | Global | 500 |

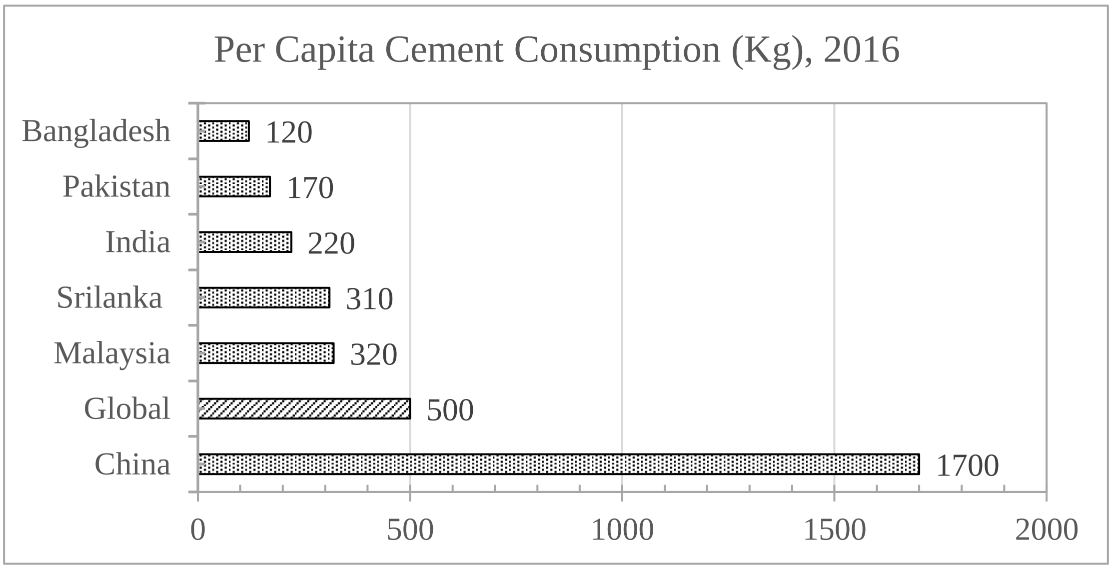



Figure 2.1: Per Capita Cement Consumption (Kg) in 2016 **[1]**.

Table 2.2: Per Capita Cement Consumption (Kg) in 2018 **[16]**.

| Sl No. | Name of Country | Consumption, Kg |
|---|---|---|
| 1 | China | 1700 |
| 2 | South Korea | 1250 |
| 3 | Malaysia | 800 |
| 4 | Thailand | 500 |
| 5 | India | 312 |
| 6 | Myanmar | 270 |
| 7 | Bangladesh | 187 |
| 8 | World Average | 563 |

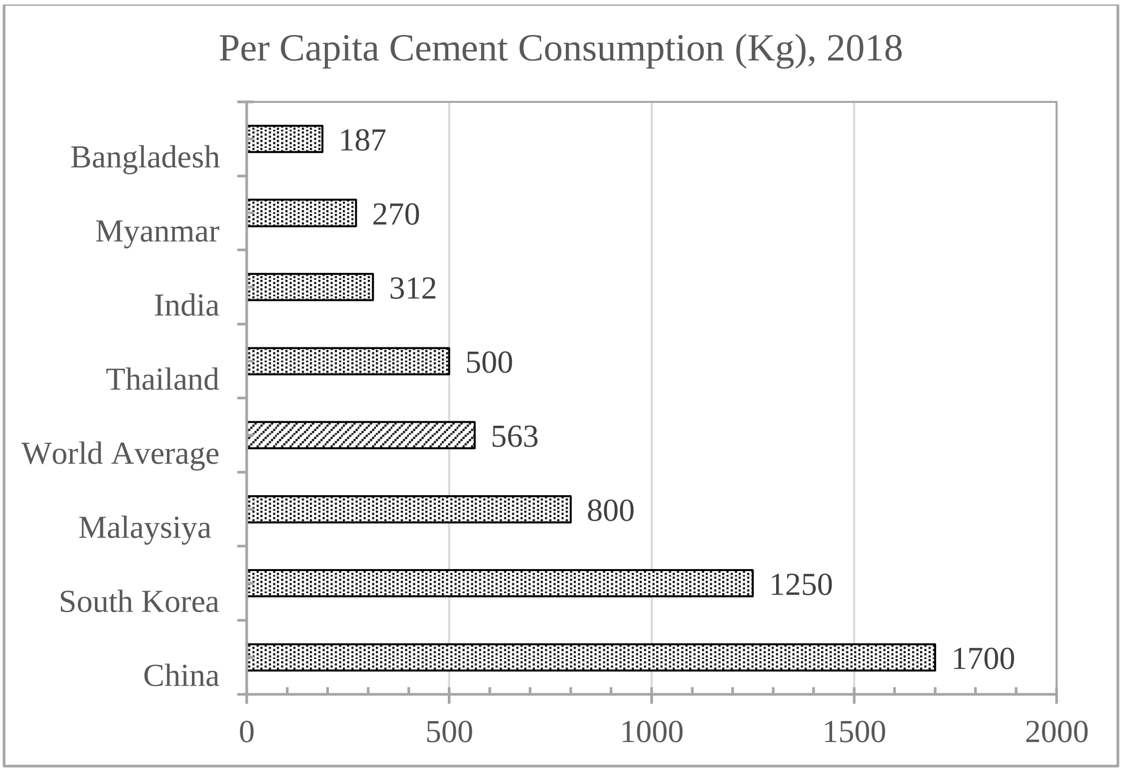



Figure 2.2: Per Capita Cement Consumption (Kg) in 2018 **[16]**.

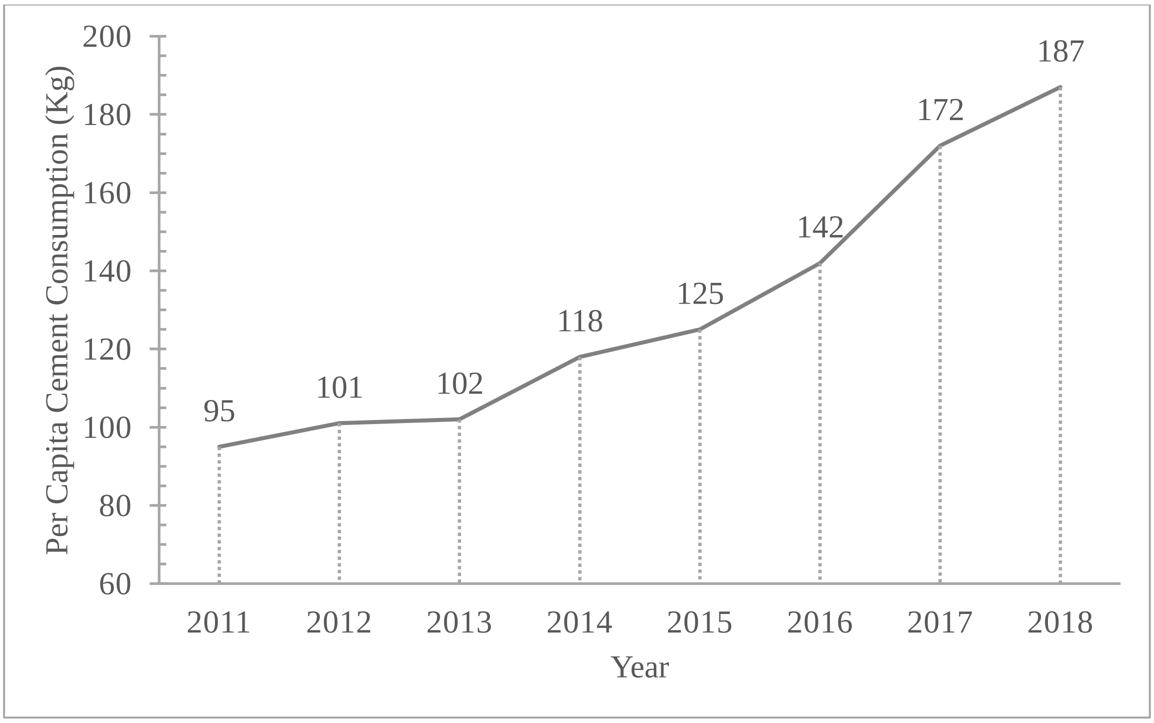



Figure 2.3: Per Capita Cement Consumption (Kg) in Bangladesh **[16]**.

In 2016 average per capita cement consumption in the world is 500 kg while that of Bangladesh is only 120 kg **[1]**. In 2018 average per capita cement consumption in the world is 563 kg while that of Bangladesh is only 187 kg. However, per capita cement consumption in Bangladesh witnessed lucrative growth over the last few years **[16]**. Concrete construction works in Bangladesh is rapidly increasing due to the necessity of development of significant number of infrastructures as well as booming of real estate business and MRT LINES (DMTCL Project) not only in the capital city Dhaka but also in other major cities, such as Chittagong, Sylhet, Cox-Bazar, Comilla, etc. Due to a huge demand of cement in concrete structures, more than 34 national and international cement companies are producing cement in Bangladesh and supplying it to the market with different brand names **[2-4]**. In Bangladesh, the per capita per year cement consumption was 22 kg in 1999, but it is increased to 120 kg in 2016 **[1, 4]**. Now it is increased to 187 kg in 2018 **[16]**.

## 2.4 Use of Cement in Bangladesh

In Bangladesh, relative rapid growth of cement industry has been observed in mid 80s. At present, the cement industry of the country is the 40th largest market in the world. Primarily five types of Portland cement are used worldwide. According to BDS EN 197-1 :2003, cements are mainly classified into five categories according to their composition, namely CEM-I, CEM-II, CEM-III, CEM-IV, and CEM-V. However, in Bangladesh two types of cement are produced known as CEM I and CEM II. CEM I is Ordinary Portland cement (OPC) with no SCM (Supplementary Siliceous Materials such as fly ash, slag, silica fume etc.). CEM II is the Portland Composite Cement (PCC) where SCM or pozzolana is added by replacing the clinker. CEM-II cement is sub-divided into different groups depending on the contents of mineral admixture and limestone powder, i.e., CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L. CEM II/A-M cement with less amount of mineral admixture (<20%) is commonly available in the market compared to CEM II/B-M which contains more amount of mineral admixture (21~35%). Cement type is Portland Composite Cement; BDS EN-197-1:2003, CEM II/B-M, strength class 42.5N, clinker 65% - 79% and lime stone 21% - 35% **[2-4]**. In areas of durability problem such as sulphate or chloride attack, PCC performs better. Before 2003, mainly OPC was used in Bangladesh. From 2003, production of Portland Composite Cement (PCC) has started in the country following the European Standard Methods (ESM). PCC gives comparable strength and durability like OPC. The basic difference between them is in the manufacturing technology. Only 65% to 80% of clinker is required to produce PCC while 95% of clinker is required to produce OPC. As a result, PCC is gaining popularity worldwide due to its environmental significance **[15]**. At present Lafarge Holcim cement company is producing PLC (Portland Limestone Cement) type cement. PLC is a slightly modified version of portland cement that improves both the environmental footprint and potentially the basic performances in concrete. It can be made at any portland cement manufacturing plant. While ordinary Portland cement (OPC) may contain up to 5% limestone, PLC contains between 5% and 15% limestone.

### 2.5 Major Manufacturers of Cement in Bangladesh

Currently, only 34 factories are in operation, including four multinational companies. At present, 81% of the total market share is held by top ten manufacturers. Among the top 10 cement market manufacturers in Bangladesh, 8 are local and 2 are multinational. Multinational cement companies are facing intensive competition with local companies which are grabbing the top slot of the industry by operating in economy of scale and with deft marketing strategy. MNCs now hold only 25-30% of the total market share. As a result of failure to penetrate market, two of the global cement group, UAE based Emirates Cement and Mexico-based cement manufacturer Cemex has recently divested their Bangladesh operations. However, completion of acquisition of Holcim by Lafarge Surma will reshape the industry dominance in Bangladesh as both the companies already operates own business here. After the completion of acquisition, Lafarge-Holcim has the 2nd place in terms of market share **[1, 16]**.

Table 2.3: Installed and expansion capacity of cement companies **[1]**.

| **Cement Company** | **Promoter** | **Products** | **Brand** | **Installed Capacity (Million MT/Yr)** | **Post Expansion Capacity (Million MT/Yr)** |
|---|---|---|---|---|---|
| Shah Cement | Abul Khair Group | OPC & PCC | Shah Cement | 5.20 | - |
| Bashundhara Group | Bashundhara Group | OPC & PCC | Bashundhara Cement & King Brand Cement | 5.05 | 7.05 |
| Lafarge Holcim Cement | LafargeHolcim | Clinker, OPC, PCC & PLC | Powercrete+, Supercrete and Holcim | Cement: 3.40 Clinker: 1.15 | - |
| Aman Cement | Aman Group | OPC | Amancem | 3.75 | - |
| Unique | Meghna Group | OPC, PCC & | Fresh Cement | 3.60 | - |

| | | | | | |
|---|---|---|---|---|---|
| Cement (Fresh) | | Portland Pozzolana Cement | | | |
| Seven Rings Cement | Shun Shing Group International Ltd. | OPC & PCC | Seven Rings Cement | 3.50 | 4.40 |
| Premier Cement | Premier Cement | OPC & PCC | Premier Cement | 2.80 | 5.80 |
| Heidelberg Cement | HC Netherlands Holding B.V (39.8%), HC Asia Holding GmbH, Germany (20.86%) | OPC & PCC | Scan Cement & Ruby Cement | 2.38 | - |
| Crown Cement | M.I. Cement Mills Ltd. | OPC & PCC | Crown Cement | 1.74 | 3.50 |
| Madina (Tiger) Cement | Madina Cement Industries Ltd. | OPC & PCC | Tiger Cement | 1.69 | - |
| Akij Cement | Akij Group | Fly-Ash Free Cement | Akij Cement | 1.20 | - |
| Royal Cement | Kabir Steel Group & BSA Group | OPC & PCC | Royal Cement | 1.00 | - |
| Anwar Cement | Anwar Group | OPC, and Portland Pozzolana Cement | Anwar Cement | 1.00 | - |
| Confidence Cement | Confidence Group | OPC & PCC | Confidence Cement | 0.75 | 1.50 |
| Eastern Cement | Doreen Group | OPC & PCC | Seven Horse Cement and Seven Horse Supreme | 0.45 | - |
| Mongla Cement | Sena Kalyan Sangstha | PCC | Elephant Brand Cement | 0.39 | - |
| S. Alam Cement | S.Alam Group | PCC | Minar Brand | 0.36 | - |
| Aramit Cement | Aramit Group | PCC | Camel | 0.20 | 0.70 |
| Mir Cement | Mir Group | OPC & PCC | Mir Cement | 0.20 | - |
| Mostafa-Hakim Cement | Mostafa-Hakim Family | OPC | Taj Mahal Cement | 0.17 | - |

## 2.6 Export of Bangladeshi Cement

Export revenue from Cement has dropped significantly in recent period. In the FY2015-16, the export of cement from Bangladesh amounted to USD 1.71 million (BDT 133.6 million) which was USD 3.94 million (BDT 307.8 million) in FY 2014-15, representing 43.4% plunge in export sales. Bangladesh started exporting cement from 2003. M.I. Cement Factory Limited was the pioneer in cement export from Bangladesh. Cement export data presents that Crown Cement (a brand of M.I. Cement) accounts for 37% of the total export volume in cement (Source: MI Cement Annual Report). Presently cement is being exported to India, Myanmar, Nepal, Maldives and Sri Lanka. Bangladesh exports 0.5 to 0.6 million MT of cement a year to the seven-sister market in India. However, the export of cement has declined in recent period as Indian manufactures are now offering cement at lower rates than Bangladeshi companies due to their anti-dumping tax benefits. Furthermore, Bangladesh's exports to Tripura through Akhaura land port is likely to drop further as the government has granted transit facility to India and the recent improvements in infrastructure on the Indian side. Availing transit facility, India is now being able to shift cement at lower costs to the “Seven Sister States” of north-eastern India through Bangladesh. The shipment cost is much lower compared to importing from Bangladesh. Myanmar is showing another prospective market for export of cement to boost up and develop the cement export **[1, 16]**.

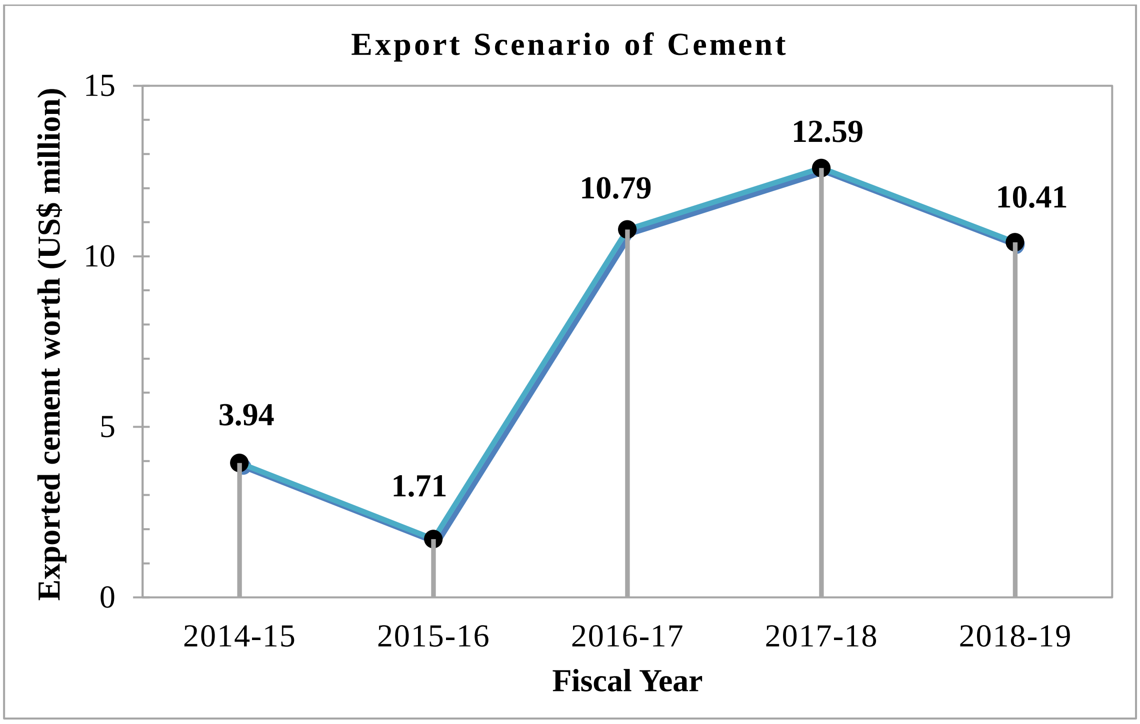



Figure 2.4: Exported cement worth in Bangladesh **[1, 16]**.

### 2.7 Summary

Bangladesh cement industry is one of the fastest growing cement markets in the world. Its growth is approximately 11.5% CAGR over the last seven years. The demand is doubled from 14.6 million MT per year to around 31.3 million MT per year. Per capita cement consumption in Bangladesh almost doubled from 95 kg in 2011 to 187 kg in 2018 **[16]**. Due to a huge demand of cement in concrete structures, huge growth of the cement industry is found last two decades. However, research work on Bangladeshi cements is very limited and still there is a big scope to work particularly on physical and chemical properties of cements as they produced in local factory and local raw materials. Therefore, it is required to investigate the quality of cement so that sustainability in construction work can be ensured in Bangladesh. This research work has been planned to enrich knowledge on the quality assessment of local cements that may be helpful for both researchers and engineers.

# CHAPTER - 3

# METHODOLOGY

## 3.1 Introduction

The main objective of this research is to investigate the physical properties of representative cements of Bangladesh by means of experimental investigations. In order to determine the physical properties of cement such as density, specific gravity, fineness, normal consistency, initial and final setting time, compressive strength of cement mortars and compressive strength (cylindrical) of cement, standard tests were performed on the representative cements as per ASTM specifications. Based on the cement production, 10 different cements manufactured by 10 different industries were collected from the market to prepare 300 samples to conduct those tests. This chapter includes sample collection, major composition, test plan, test set-up, sample preparation and experimental procedure.

## 3.2 Representative Sample Collection

According to Bangladesh Standard, BDS EN 197-1:2003, cements are mainly classified into five major categories according to their composition, namely CEM-I, CEM-II, CEM-III, CEM-IV and CEM-V. CEM-II is basically Portland Composite Cement (PCC). CEM-II cement is sub-divided into different groups depending on the contents of mineral admixture and limestone powder, i.e., CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L **[4]**. Quality assessment of CEM II/B-M type cement is justified in this analysis. There are currently 34 active and recognized companies who are operating as cement manufacturer in Bangladesh **[1]**. Among them, samples of 10 major cement brands from CEM II/B-M category were collected from the market as experimental sample. These cement industries are considered the main stake holder of the current cement industries of Bangladesh based on the production capacities. It is important to highlight that all the cement industries have already started their product in the global market here quality of cement as per standard is a vital issue. During collection the samples, the manufacturing and expiry date were observed very carefully so that the date of manufacturing and expiry are nearly same for all cements (± 3 days). Each cement bag was kept in an air-tight plastic bag to prevent unwanted hydration with the moisture which is normally prominent in local weather condition.

### 3.3 Composition of Different Cements

According to BDS EN 197-1:2003, CEM-II is Portland Composite Cement. CEM-II cement is sub-divided into different groups depending on the contents of mineral admixture and limestone powder, i.e., CEM II/A-M, CEM II/B-M, CEM II/A-S, CEM II/A-L. Quality assessment of CEM II/B-M type cement is used as sample in this analysis. Ingredients of cement printed on the collected cement bags were recorded. As per BDS EN 197-1 :2003, CEM II/B-M type cement contains clinker 65% - 79%, blast furnace slag, fly ash and lime stone 21% - 35% and minor additional constituents 0% - 5%. Strength class of this cement is 42.5N. All the representative cement brands contain clinker 65% - 79%, blast furnace slag, fly ash and lime stone 21% - 35% and minor additional constituents 0% - 5%. All cement bags levelled approximately same ingredient as they maintained BDS. Since the variation of the ingredients contains wide rage, there is a chance to possess different physical properties even the different industries keep them in the range value.

### 3.4 Testing Procedures of Cement

In this study, normal consistency, initial and final setting time, cement mortar, compressive strength by cylinder, specific gravity and fineness, density tests are conducted to investigate the physical properties of cement. Generally, those test are conducted as per specific guideline of ASTM. Test name and their specifications are shown in Table **3.1**. Test procedures, test set-up and sample preparation are described one by one in the next sections.

Table 3.1. Test name and ASTM codes

| Sl. No. | Name of test | Test Method & Specification |
|---|---|---|
| 1 | Density & specific gravity | ASTM C 188-95 |
| 2 | Fineness | ASTM C 204-07 |
| 3 | Normal consistency | ASTM C 187-04 |
| 4 | Initial and final setting time | ASTM C 191-04 |
| 5 | Compressive strength of cement mortars | ASTM C 109-07 |
| 6 | Compressive strength (cylindrical) | ASTM C 39-04 |

### 3.4.1 Density and Specific Gravity

The density is the fundamental physical characteristic of material. Density represents the degree of compactness of material. If the material possesses higher density, it is more compacted material. Cement content has a pronounced effect on overall density of the concrete and concrete structures. It has a density of about 3150 kg/m$^3$ which is even more than that of aggregate. Accordingly, a great portion of the overall density of the concrete actually came from cement **[48].** So, it is important to find out the density of cement so that the physical standard of any cement brand can be obtained.

Specific gravity of the cement is the ratio of cement density and water density at 4°C. At this temperature, the density of water is 1 Mg/m$^3$ or 1g/cm$^3$. Specific Gravity is basically the ratio of Cement density/Water density **[49]**. Based on the moisture content present in the cement, the specific gravity can either increase or decrease. The cement particles have pores or particles that can contain water within it. A nominal mix is prepared with a cement of specific gravity 3.15. Any change in this value of specific gravity will affect the mix design. Hence, it is necessary to test the specific gravity of the cement procured before mixing process **[50]**. Cement reacts with water as process of hydration. Therefore, in order to prevent this reaction kerosene is used to mix with cement. Two samples from each cement manufacturing industry were prepared. Therefore, a total of 20 samples were prepared for density test for representative cement sample. Density test procedure of cement is shown in **Figure 3.1** according to ASTM C 188-95.

**Density test procedure of cement**

↓

**Preparation of sample**

At first, the flask was filled with kerosene up to 0.50 ml graded. The inside of the flask above the level of the liquid, must need to clean or dry after pouring. Then, 64g cement were poured or introduced inside the Le Chatelier flask.

↓

**Density determination**

Final reading was taken after the flask has been immersed in the kerosene.
First reading of liquid = 0.50 ml.

Displaced volume of liquid = First reading of liquid - Final reading of liquid

Density of Cement = 62.5 / Displaced volume of liquid gm/cm$^3$

= 62.5 / (Final reading of liquid – 0.50) gm/cm$^3$

Figure 3.1: Density test procedure of cement **[49]**.


(a) (b)

Figure 3.2: Photographs of sample test set-up for density test

**Figure 3.2** highlights the sample test set-up for density test of two representative cement samples. **Figure 3.2(a)** shows that the final reading after the absorption of kerosene is 21.90 ml. So displaced volume of liquid is (21.90 ml – 0.50 ml) 21.40 ml. **Figure 3.2(b)** shows that the final reading after the absorption of kerosene for representative cement sample is 21.20 ml. So displaced volume of liquid is (21.20 ml – 0.50 ml) 20.70 ml. Total 20 samples were prepared for density test of representative cement sample as per the density test procedure.

### 3.4.2 Fineness of cement by air-permeability apparatus

Fineness test of cement is performed to determine the particle size of cement. Generally, it is a requirement for the cement to be fine. As the fineness of cement increases the quality of the cement also improves. However, excessive increase of fineness can also lead to the requirement of more water for workability, resulting in a higher possibility of dry shrinkage. Fineness test is used to check the proper grinding of cement and measures the surface area of the cement particles per unit mass. This test method covers determination of the fineness of cement, using the Blaine air permeability apparatus, in terms of the specific surface expressed as total surface area in square centimeters per gram or square meters per kilogram of cement. A total of 40 samples were prepared for fineness test for representative cement sample. Total 4 sample was prepared for each representative cement sample for fineness test. Fineness test procedure of cement is shown in **Figure 3.4** according to ASTM C 204-07.

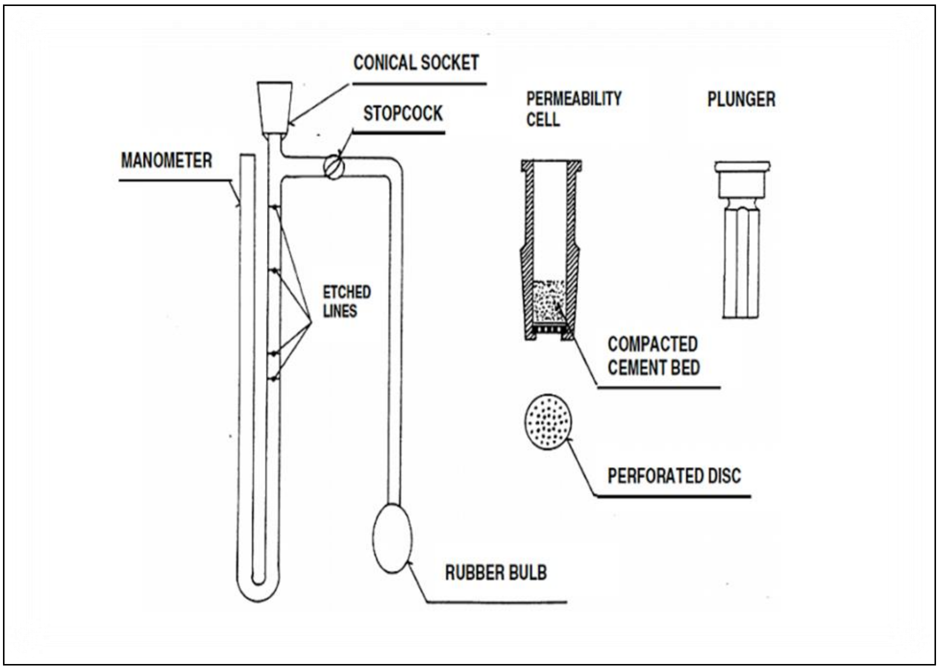



Figure 3.3: Blaine air permeability apparatus **[51, 52]**.

**Fineness test procedure of cement**

↓

**Preparation of sample**

At first the perforated disk was seat on the ledge in the permeability cell (shown in **Figure 3.3)**. Inscribed or marked face should be down. Then, a filter paper was placed on the metal disk and pressed the edges down with a rod. Rod having a diameter slightly smaller than that of the cell. After determining the quantity of cement, was to place in the cell. Placing a filter paper disk on top of the cement, the cement was compressed with the plunger until the plunger collar was in contact with the top of the cell. Using of fresh paper filter disks was required for each determination.

↓

**Permeability determination**

The permeability cell was attached to the manometer tube (Shown in **Figure 3.3**). Making certain that an airtight connection was obtained. The air was evacuated in the one arm of the manometer U-tube (Shown in **Figure 3.3**) until the liquid was reached the top mark and then the valve was closed tightly. The timer was started when the bottom of the meniscus of the manometer liquid reached the second (next to the top) mark and stopped when the bottom of the meniscus of liquid reached the third (next to the bottom) mark. Finally, the time interval was measured and recorded in seconds. It was made at least three determinations of the time of flow on each of three separately prepared beds of the cement.

Figure 3.4: Fineness test procedure of cement **[53]**.

### 3.4.3 Normal consistency test of cement

This test method covers the determination of the normal consistency of hydraulic cement paste with Vicat's apparatus **(Shown Figure 3.5)**. The amount of water content that brings the cement paste to a standard condition of wetness is called "normal consistency". It has a marked effect upon the time of set as well as upon other properties of cement. The paste at normal consistency is fairly stiff and is used only for the determination of time of set and soundness of cement **[54]**. It is necessary to fix the quantity of water to be mixed in cement while experimenting on it. The test setup is shown in **Figure 3.5**. The normal consistency of a cement paste is defined as that consistency i.e. percentage (%) of water which will permit the vicat's plunger **(Shown Figure 3.5)** to penetrate to a point 10 mm from the top of the vicat mold **(Shown Figure 3.5)**. This test method conforms to the ASTM standard requirements of specification C187-04. In this study, a total of 50 samples were prepared for normal consistency test of ten different representative cement brands of Bangladesh. Total 5 sample were prepared for each representative cement sample for normal consistency test. Normal consistency test procedure of cement is shown in **Figure 3.6** according to ASTM C 187-04.

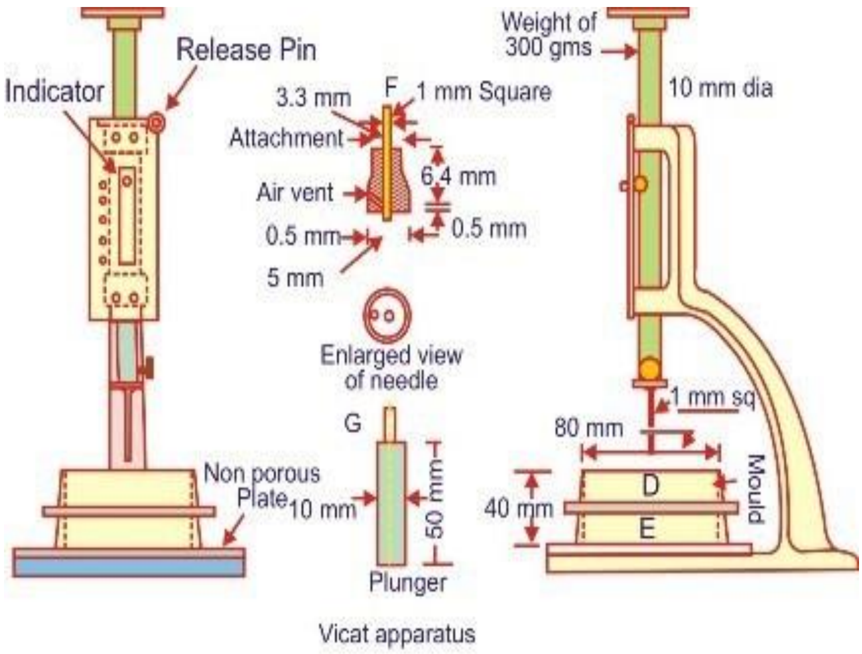



Figure 3.5: Vicat apparatus **[55]**.

Sample preparation for normal consistency test and normal consistency determination photographs are shown in **Figure 3.7**. Before starting the cement paste preparation, 650 gm cement have to weigh for each sample preparation **[Shown Figure 3.7 (a)]**. Before mixing water to cement **[Shown Figure 3.7 (b)]**, 24%, 26%, 28%, 30% and 32% or 156 gm, 169 gm, 182 gm, 195 gm and 208 gm have to measure respectively. **Figure 3.7 (c)** shows the cement mortar mixing for sample preparation and **Figure 3.7 (d)** shows the normal consistency determination procedure.

**Normal consistency test procedure**

↓

**Preparation of cement paste**

First 650 gm cement were added to the water. As per test specification, water is required 24%, 26%, 28%, 30% and 32% of cement respectively. 30s time was allowed for the absorption of the water **[56]** and mixed the cement with water properly or complete the operation by continuous, vigorous mixing, squeezing and kneading with the hands for 1.5 min **[57]**.

↓

**Molding test specimens**

The mold was kept on the glass plate and filled the mold with cement paste. Then top of the specimen was made smooth with one or two light touches of the pointed end of the trowel. During the operation of cutting and smoothing, care was taken so that the paste was not compressed.

↓

**Normal consistency determination**

In the test program, the paste resting on the plate was centered and confined in the ring, under the rod. The plunger end was brought in contact with the surface of the paste. Tightening the set-screw, the rod was to set the movable indicator to the upper zero mark of the scale. Then, the rod was released immediately. This must not exceed 30s after completion of mixing. The paste was to be of normal consistency when the rod settles to a point 10±1 mm below the original surface in 30s after being released. Finally, trial pastes were made with varying percentages of water.

Figure 3.6: Normal consistency test procedure of cement **[56, 57]**.


a) Weighing cement b) Pouring water c) Mixing cement paste

d) Test set-up

Figure 3.7: Photographs of sample preparation (a, b and c) and test set-up (d) for normal consistency test

### 3.4.4 Setting time test of cement

The objective of this experiment is to determine the initial and final setting time of cement. Cement, when mixed with water, forms slurry which gradually becomes less plastic with the passage of time and finally a hard mass is obtained to form concrete. In this process, a stage is reached when the cement paste is sufficiently rigid to withstand a definite amount of pressure. The time required for cement to reach this stage is termed “Setting time”. The term ‘‘Setting” is used to describe the stiffening of the cement paste. Setting of cement refers to changes of cement paste from a semi-liquid to rigid state.

Setting differs from hardening of cement which refers to the gain of strength of a set of cement paste; although during setting the cement paste acquires some strength **[54]**. This test method conforms to the ASTM standard requirements of specification C191. A total of 10 samples were prepared for setting time test of representative cement. Setting time test procedure of cement is shown in **Figure 3.8** according to ASTM C 191-04.

**Setting time test procedure**

↓

**Preparation of cement paste**

At first, 650 gm cement was added to the water. Water quantity could get from respective normal consistency. It was allowed 30 s for the absorption of the water **[58]**. The cement was mixed with water and completed the operation by continuous, vigorous mixing, squeezing and kneading with the hands for 1.5 min **[57]**.

↓

**Molding test specimens**

The mold was kept on the glass plate and filled the mold with cement paste. Then top of the specimen was made smooth with one or two light touches of the pointed end of the trowel. During the operation of cutting and smoothing, care was taken so that the paste was not compressed. The time was noted down if finished and the specimens were kept for 30 minutes without being disturbed.

↓

**Time of setting determination**

Tightening the set screw and the indicator was set at the upper end of the scale and released the rod quickly by releasing the set screw. The needle was allowed to settle after molding for 30 s. The reading taken to determine the penetration. It was made each penetration test at least 5 mm away from any previous penetration and at least 10 mm away from the inner side of the mold. The penetration was determined every 15 minutes after until 25 mm or less penetration. 25 mm penetration is the initial setting time and 0.50 mm penetration is the final setting time.

Figure 3.8: Setting time test procedure of cement **[57, 58]**.

**Figure 3.9** represents test set-up of the samples for setting time test of cement. It is shows that total 10 samples are prepared for setting time test. For taking penetration reading, paper is kept beside the sample. After finishing the molding, it was kept the specimen for 30 minutes without being disturbed and first penetration reading was taken after 45 minutes serially. 25 mm penetration is the initial setting time and 0.50 mm penetration is the final setting time. After 15 min penetration readings were taken and noted and this procedure was repeated until final setting time or 0.50 mm penetration was obtained.

Figure 3.9: Photographs of sample test set-up for setting time test

### 3.4.5 Compressive strength of cement mortars

The objective of this experiment is to determine the compressive strength of cement mortars using cube specimens. The samples are 2 inch square sized. Test for structural strength is not made on a neat cement paste because of difficulties in molding and testing with consequent large variations in results. This test is carried out to find out the compressive strength of cement paste indirectly. As shrinkage cracks are formed in dried cement paste, test can't be properly carried out on a block of cement paste **[54]**. Therefore, the test is carried out on blocks of mortars made of cement, sand and water, cured for 3 days, 7 days and 28 days. For the preparation of cement mortar samples, graded standard sand was mixed with cement. A total of 90 samples were prepared for compressive strength test of representative cement. In this part of investigation, 30 samples for each age that made a total 90 samples were prepared for compressive strength test of cement mortar. Compressive strength test procedure of cement mortar is shown in **Figure 3.11** according to ASTM C 109-07.

Table 3.2: Quantities of cement, sand and water **[59]**.

| | If no. of specimens 6 | If no. of specimens 9 |
|---|---|---|
| Cement, g | 500 | 740 |
| Sand, g | 1375 | 2035 |
| Water, ml for Portland (0.485) | 242 | 340 |

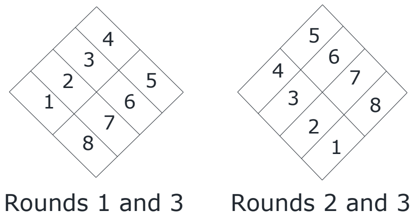



Figure 3.10: Order of tamping in molding of test specimens **[59]**.

**Compressive strength test procedure of cement mortar**

↓

**Preparation of cement mortar**

As per specification, cement: sand: water = 1: 2.75: 0.485. Therefore, cement= 740 gm, Ottawa sand= 2035 gm and water= 359 gm as shown in **Table 3.2 [59]**. The dry paddle and the dry bowl were placed in the mixing position in the mixer. The cement was added to the water. Starting the mixer, it was mixed at the slow speed (140±5 r/min) for 30 s. Then the entire quantity of sand was added slowly over a 30 s and the mixer was changed to medium speed (285±10 r/min) and mixed for 30s. Mixer was stopped and mortar was stood for 90 s. It was finished by mixing for 60 s at medium speed **[57]**.

↓

**Molding Test Specimens**

Molding of the specimens was started within 2.5 min after completion of the mixing. At first, the mold was filled with mortar about 1 in depth. Tamping the mortar in each cube compartment 32 times in about 10 s in 4 rounds which is shown in **Figure 3.10**. During tamping of the second layer, bringing in the mortar was forced out onto the tops of the molds and cut off the mortar to a plane surface flush with the top of the mold by drawing the straight edge of the trowel.

↓

**Storage of test specimens**

After molding, immediately the specimens were kept in the moist room. After 24 h the specimens were removed from the mould and kept the storage water for curing.

↓

**Compressive strength determination**

Before starting the test, the specimens were removed from the water not more than 15 min before the test was carried out. Then the cross-sectional area was checked of the specimens. The load rate was 200 to 400 lbs/s (900 to 1800 N/s).

Figure 3.11: Compressive strength test procedure of cement mortar **[57, 59]**

### 3.4.6 Compressive strength of cylindrical concrete specimens

The objective of this experiment is to determine the compressive strength of cement concrete specimens. The compressive strength of concrete is one of the most important and useful properties of concrete. In reinforced concrete structures, concrete is employed primarily to resist compressive stresses. Nevertheless, strength of any structure usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste **[54]**.

The test method conforms to the ASTM standard requirements of specification ASTM C39. Composition of mortars are- Cement: Sand: Coarse aggregate = 1: 1.5: 3 (by weight) and Water–Cement ratio = 0.45. As per composition of mortar, 28-days compressive strength 24 MPa (3500 psi) is considered. Sylhet (FM ≥ 2.50) sand as fine aggregates and 20 mm down-graded boulder stone chips (Pakora, India) as coarse aggregates are used for testing compressive strength of cylindrical concrete specimens. In this part of the experimental investigation, 30 samples were prepared to investigate for each age (7, 14 and 28) days of compressive strength of representative cement sample of cylindrical concrete specimens. Compressive strength test procedure of cylindrical concrete specimens is shown in **Figure 3.12** according to ASTM C 39-04. Therefore, a total of 90 samples were prepared for compressive strength test of cylindrical concrete specimens of representative cement sample.

**Figure 3.14** represents the sample preparation for compressive strength of cylindrical specimens. It shows that after filling the mold with mortar, smoothing the top of the specimen with one or two light touches of the pointed end of the trowel. Each mold was filled with concrete in three layers and tamping each layer 25 times with 16mm (5/8 in.) steel tamping rod and placed in the moist storage for 24±8 hours at a temperature of 23±1.7°C.

**Compressive strength test procedure of cylindrical specimens**

**Preparation of cement mortar**

Cement: Sand: Coarse aggregate = 1: 1.5: 3 (by weight) and Water-Cement ratio = 0.45. The dry paddle and the dry bowl were placed in the mixing position in the mixer. The cement was added to the water. Starting the mixer, it was mixed at the slow speed (140±5 r/min) for 30 s. Then the entire quantity of sand was added slowly over a 30 s and the mixer was changed to medium speed (285±10 r/min) and mixed for 30 s. Mixer was stopped and mortar was stood for 90 s. It was finished by mixing for 60 s at medium speed **[57]**.

**Preparation of cylindrical specimens**

Each mold was filled with concrete in three layers and tamping each layer 25 times with 16mm (5/8 in.) steel tamping rod. The 2$^{nd}$ and 3$^{rd}$ layer of the mold were filled accordingly. The tops of the mold were smoothed off evenly.

**Storage of test specimens**

After molding, all specimens were placed in the moist storage for 24±8 hours at a temperature of 23±1.7°C. Then the specimens were removed from the mold and immersed in saturated lime water until testing.

**Compressive strength determination**

Before starting the test, the specimens were removed from the water not more than 15 min before the test was carried out. Then the cross-sectional area was checked of the specimens. The load rate was 35±7 psi/s. Fracture types were observed very carefully (Shown in **Figure 3.13**).

Figure 3.12: Compressive strength test procedure of cylindrical specimens **[57, 60]**.

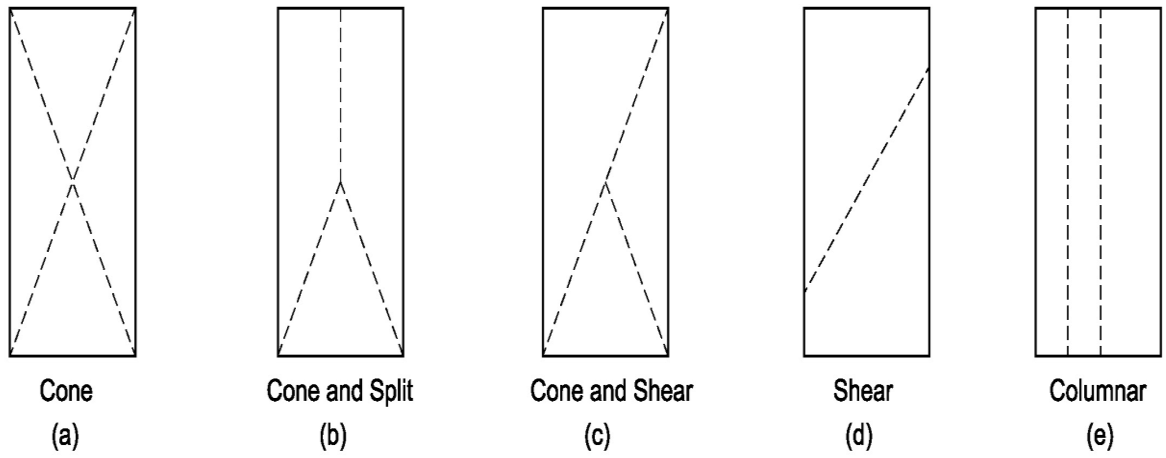



Figure 3.13: Sketches of types of fracture **[60]**.

Type of failure and the appearance of the concrete are shown in **Figure 3.13**. According to failure mode, a short description is given below.

**(a) Cone type-** A cone failure results lateral expansion of the concrete is restrained as the vertical compressive force is applied. Fairly typical fracture types for normal concrete.

**(b) Cone and Split type-** Fairly typical fracture types for normal concrete.

**(c) Cone and Shear type-** Fairly typical fracture types for normal concrete.

**(d) Shear type-** This type of fracture generally indicates the cylinder failed prematurely, yielding results lower than the actual strength of the concrete. Concretes with high sand contents may fail in the shear mode.

**(e) Columnar type-** When the cylinder is allowed to expand more laterally and exhibit a splitting failure. This reduces the lateral confining pressure that's usually present and thus reduce the apparent strength.

Figure 3.14: Photographs of sample preparation for compressive strength of cylindrical concrete specimens

### 3.5 Summary

This chapter highlights the testing procedures, test setup and sample preparation of normal consistency, initial and final setting time, compressive strength of cement mortars, compressive strength (cylindrical), density, specific gravity and fineness of cement as per ASTM standards. To investigate physical properties of overall cements of Bangladesh, representative cement samples are collected from the leading ten cement manufacturers of the country. In view of maintaining similar age of the cements, manufacturing and expiry date of each cement are checked. All test procedures are highlighted in this chapter. Test samples were prepared as ASTM guideline. Each set of samples contains all ten cement brands of Bangladesh that makes a total 300 numbers of samples. Detail sample numbers of different tests and category are presented in Table 3.3.

Table 3.3. Test Name and Sample Quantity

| Representative Cement Sample | Sample No. for the Test of Cement | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Density & Specific Gravity | Fineness | Normal Consistency | Setting Time | Compressive strength (mortars) | | | Compressive strength (cylindrical) | | | Total Tested Sample |
| | | | | | 3 days | 7 days | 28 days | 7 days | 14 days | 28 days | |
| RCS-1 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-2 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-3 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-4 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-5 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-6 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-7 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-8 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-9 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| RCS-10 | 2 | 4 | 5 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | **30** |
| **G. Total** | **20** | **40** | **50** | **10** | **30** | **30** | **30** | **30** | **30** | **30** | **300** |

# CHAPTER - 4
# EXPERIMENTAL RESULTS AND DISCUSSIONS

## 4.1 General Remarks

Based on the experimental set-up and test procedure as presented in Chapter 3, Tests are conducted on 300 samples to obtain the physical properties of ten representative cement industries of Bangladesh. As test procedure, relevant ASTM guidelines are followed to assess the physical quality assessment of CEM II/B-M type cements. The physical properties of cements incudes specific gravity, fineness, normal consistency, setting time and compressive strength of cement. The experimental results obtained from this study are also analyzed to investigate the statistical parameters. The results are compared with the ASTM guideline values and previous available study. In addition, correlations are also developed to find relationships between compressive strength of concrete and their age of curing. The variation of initial and final setting times and their influence on concrete strength are also investigated. The relationship between mortar strength and concrete strength from the same batch of cement are also investigated.

## 4.2 Density and Specific Gravity Test Results

### 4.2.1 Density of cement

Density of cement samples were conducted as per ASTM C 188-95. The detail test procedure is presented in chapter 3 Section 3.4.1. Density test of cements are performed for all representative cements samples on 20 samples (2 samples from each manufacturer).

The density is the fundamental physical characteristic of the material. Density is defined by mass of a unit volume of a material substance, expressed as kg/m$^3$ or gm/cm$^3$.

$$p = \frac{\mathrm{m}}{\mathrm{v}} \qquad \text{………………..……………….…………} \quad (4.1)$$

where,

ρ = density of cement, m = mass of the cement, gm and v = displaced volume, $cm^3$

The variation of density of all representative cement samples is shown in **Figure 4.1**. It is found that the density of all representative cement samples is very close and the differences among the densities are very low. The density of cement varies in range 2.91 to 3.15 $gm/cm^3$ with a mean density of 3.023 $gm/cm^3$. Only one out of ten industries shows a density below 3.0 $gm/cm^3$ (RCS-3) which is only 10% of the total cement samples. The range is also very close to the ASTM standard value of 3.15 $gm/cm^3$. Therefore, it can be concluded that the density of Bangladeshi cement shows a very good standard following ASTM guideline.

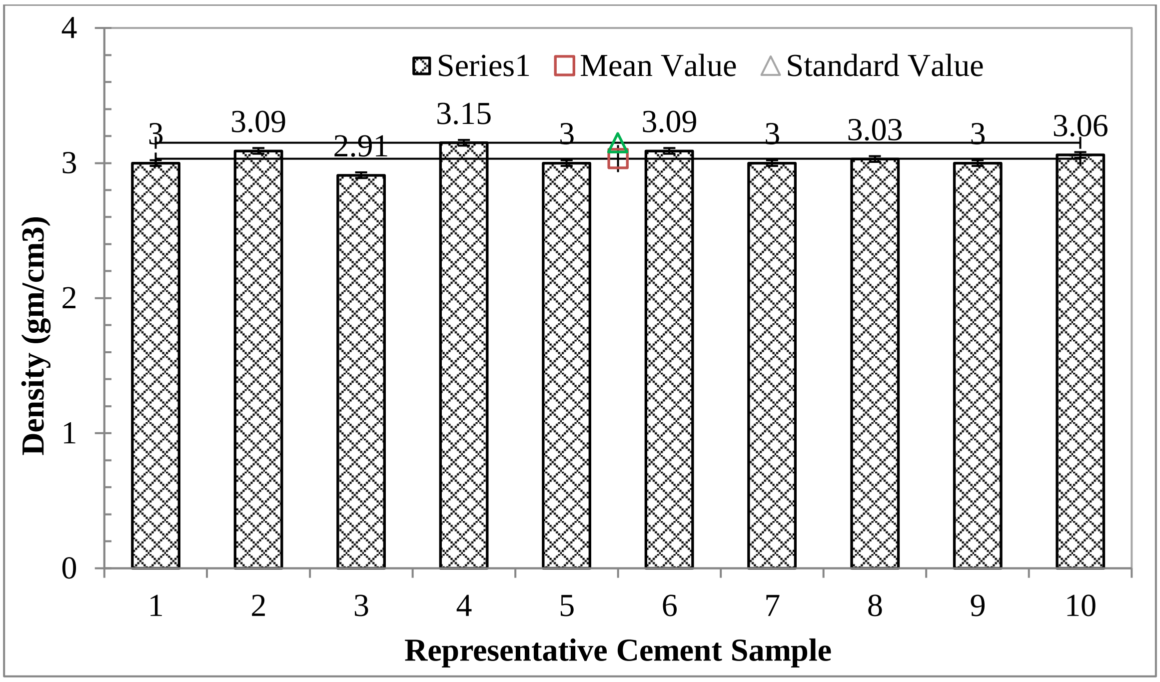



Figure 4.1: Density of representative cement samples

### 4.2.2 Specific Gravity of Cements

Specific gravity test of cement samples was conducted as per ASTM C 188-95. The detail test procedure is presented in chapter 3 Section 3.4.1. Specific gravity of the cement is the ratio of cement density and water density at 4°C. At 4°C.

$$\text{Specific Gravity} = \frac{\text{Cement density}}{\text{Water density}} \qquad \text{..............................} \; (4.2)$$

The specific gravity of cement of all ten manufacturers is shown in **Figure 4.2.** It is observed from the figure that the specific gravity of Bangladeshi cement varies in a range of 2.91 to 3.15. According to the ASTM standard, the specific gravity of cement is generally about 3.12-3.19. The mean value 3.023 is very close to the ASTM standard.

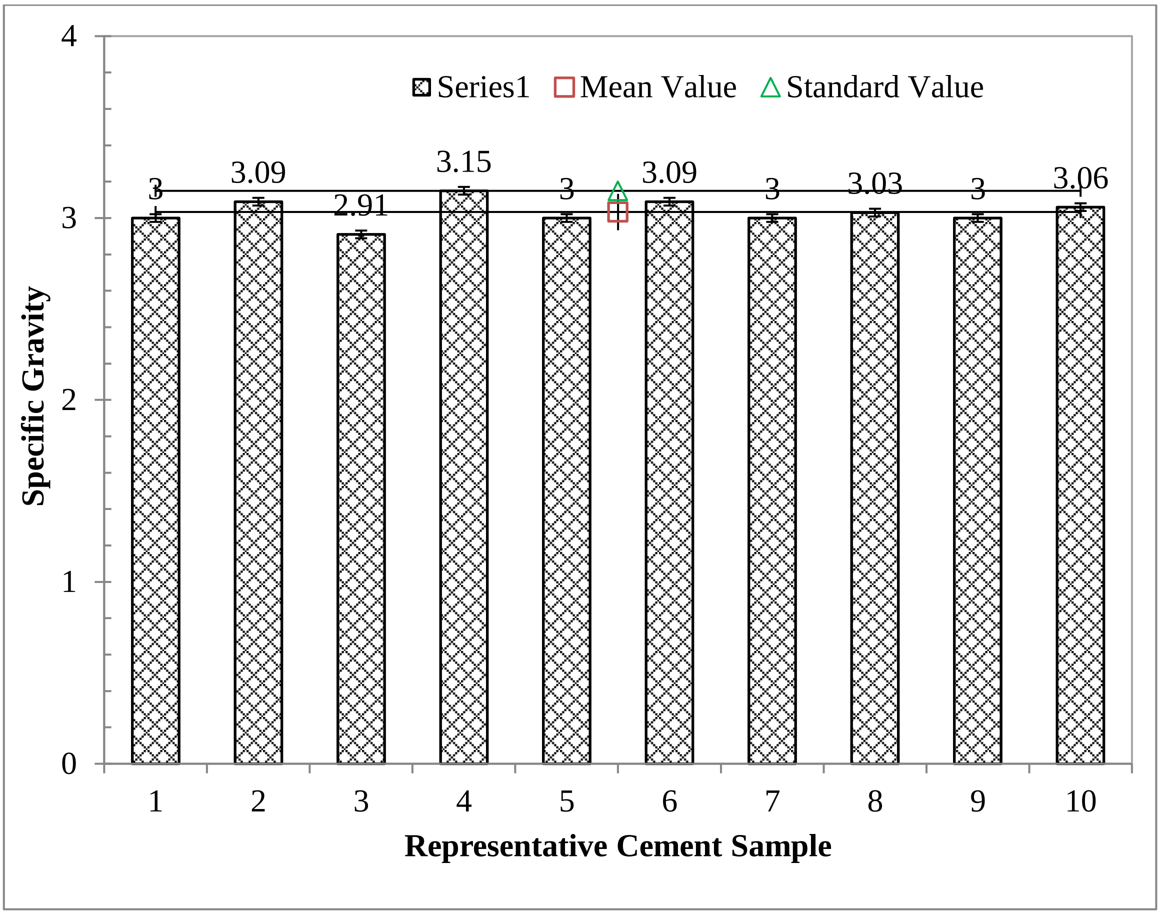



Figure 4.2: Specific gravity of representative cement samples

### 4.3 Fineness Test Results

Fineness test of cement samples were conducted by Blaine air permeability apparatus as per ASTM C 204-07. The detail test procedure is presented in chapter 3 Section 3.4.2. The fineness of cement is usually described by the specific surface of cement particle expressed as total surface area in square centimeters per gram, or square meters per kilogram of cement.

$$W = \rho V\,(1 - \epsilon) \quad \text{..............................................} \quad (4.3)$$

W= weight of cement, gm

ρ= density of cement (for Portland cement 3.15 g/cm$^3$ shall be used)

V= volume of the cement bed=1.8525 and ϵ= porosity (0.500±0.005)

We know,

$$S = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}} \quad \text{.................................} \quad (4.4)$$

Where,

S = specific surface of the test sample, m$^2$/kg

$S_s$ = specific surface of the standard sample used in calibration of the apparatus, m$^2$/kg

T = measured time interval, s, of manometer drop for test sample

$T_s$ = measured time interval in s, of manometer drop for standard sample used in calibration of the apparatus

η= viscosity of air, micro pascal seconds (μPa·s), at the temperature of test of the test sample

$\eta_s$ = viscosity of air, micro pascal seconds (μPa·s), at the temperature of test of the standard sample used in calibration of the apparatus

ϵ= porosity of prepared bed of test sample

ϵ$\epsilon_s$ = porosity of prepared bed of standard sample used in calibration of apparatus ρ= density of test sample (for portland cement a value of 3.15 Mg/m$^3$ or 3.15 g/cm$^3$ shall be used)

$\rho_s$ = density of standard sample used in calibration of apparatus (assumed to be 3.15 Mg/m$^3$ or 3.15 g/cm$^3$)

b = a constant specifically appropriate for the test sample (for hydraulic cement a value of 0.9 shall be used) and

$b_s$ = 0.9, the appropriate constant for the standard sample and $S_s$ = 3818 (Constant)

The variation of fineness of all cement manufacturer is shown in terms of bar chart on **Figure 4.3**. The mean value of fineness of cement is shown in the figure as well. The figure shows that the fineness of different cements varies in range of 241 -364 $m^2$/kg. According to ASTM C 150, standard Blaine fineness range is 260-430 $m^2$/kg. From **Figure 4.3**, it is found that fineness of two representative cement samples falls below the ASTM range. However, their values are also close to the lower range of ASTM C 150 requirements. Therefore, 80% representative cement sample of Bangladesh satisfies the ASTM requirements. The mean value of fineness is found to be 303 $m^2$/kg satisfies the ASTM standards which illustrates the standard of Bangladeshi cements.

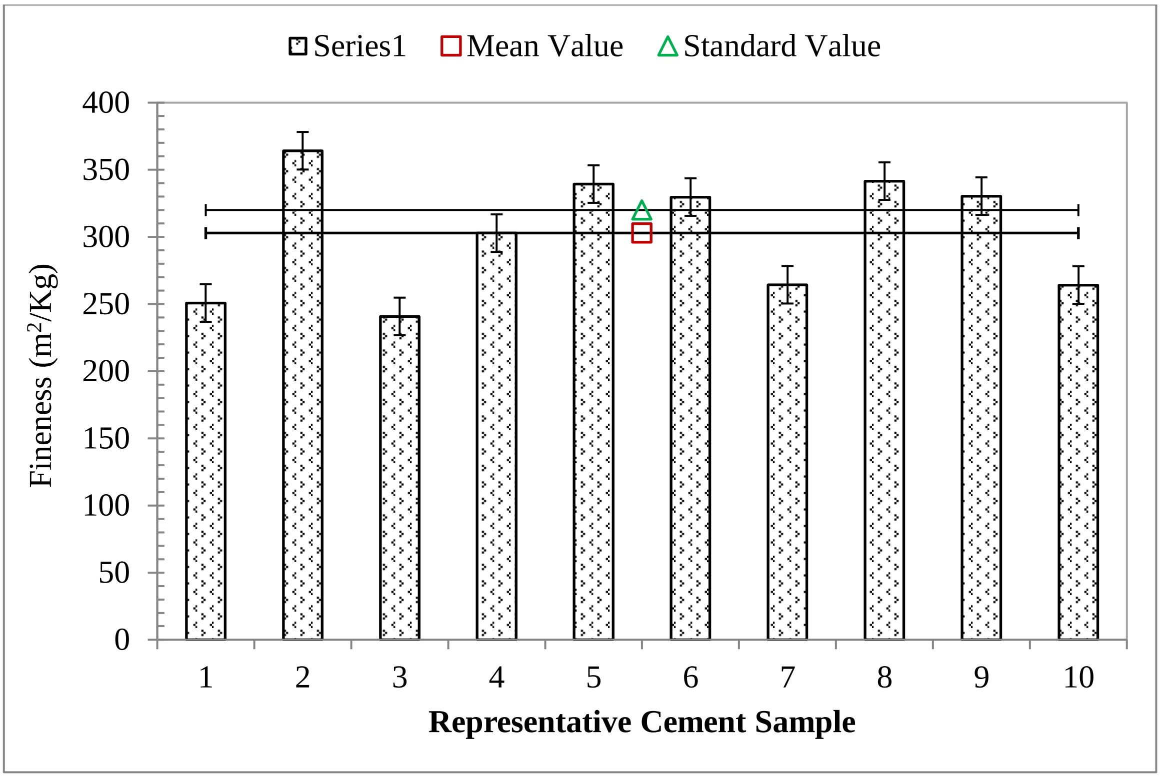



Figure 4.3: Fineness of representative cement samples

## 4.4 Normal Consistency Test Results

Normal consistency test of cement samples was conducted as per ASTM C 187-04. The detail test procedure is presented in Chapter 3 Section 3.4.3. The variation of penetration with water content of 10 representative cement samples for normal consistency test is shown in **Figure 4.4**. It is found that the penetrations of nine representative cement samples (out of ten) are almost same because their trend lines pass very closely. The penetrations of 1 representative cement sample (RCS-7) are different from the others. Therefore, RCS-7 does not follow ASTM guidelines. The figure shows that with the increase of penetration depth, normal consistency of cement decreases. The variation of normal consistency of representative cement sample with mean value is shown in **Figure 4.5**. According to the ASTM C 187, normal consistency of cement is 22~30%. The result shows that almost 90% of the representative cement samples are very close to the ASTM limit of normal consistency. Instead of falling the consistence of cement in a range of 22-30%, all Bangladeshi cements maintains cement's consistency within 28 ~32% which are very close to the ASTM range (22-30%). From **Figure 4.5**, it can be seen that the mean value of normal consistency is 31%. It represents that normal consistency is just higher than the ASTM range. Though normal consistency is just crossed the range value of ASTM guideline, all representative cement samples satisfy the ASTM requirements (ASTM C 595-12) of the limit of compressive strength of cement which is shown in **Figure 4.10**.

The comparison of normal consistency in terms of their mean value is compared with the similar study previously conducted by Mohammed **[4]** as shown in **Figure 4.6**. It is found that average normal consistency obtained from this study is greater than that previously claimed by Mohammed **[4]**. The comparison shows that the average normal consistency of current study is 14.43% greater than the study conducted nearly a decade ago.

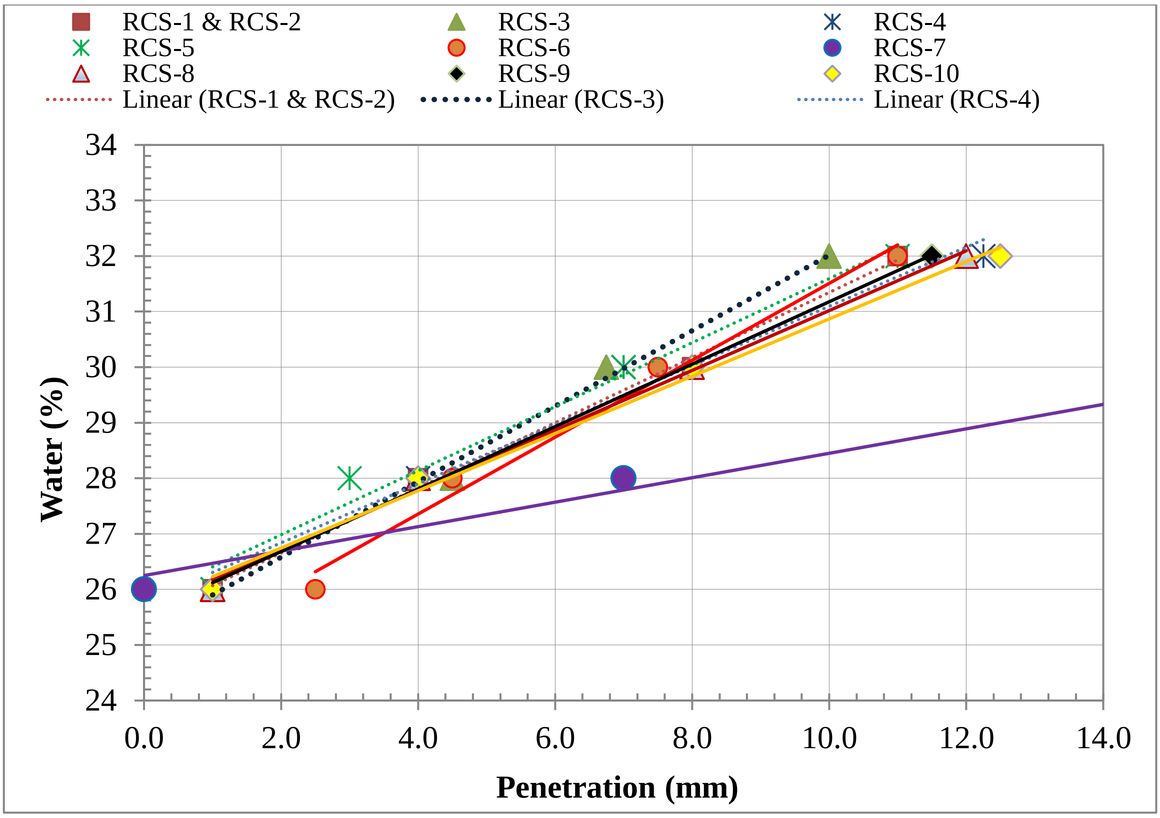



Figure 4.4: Normal consistency of RCS-1 to RCS-10

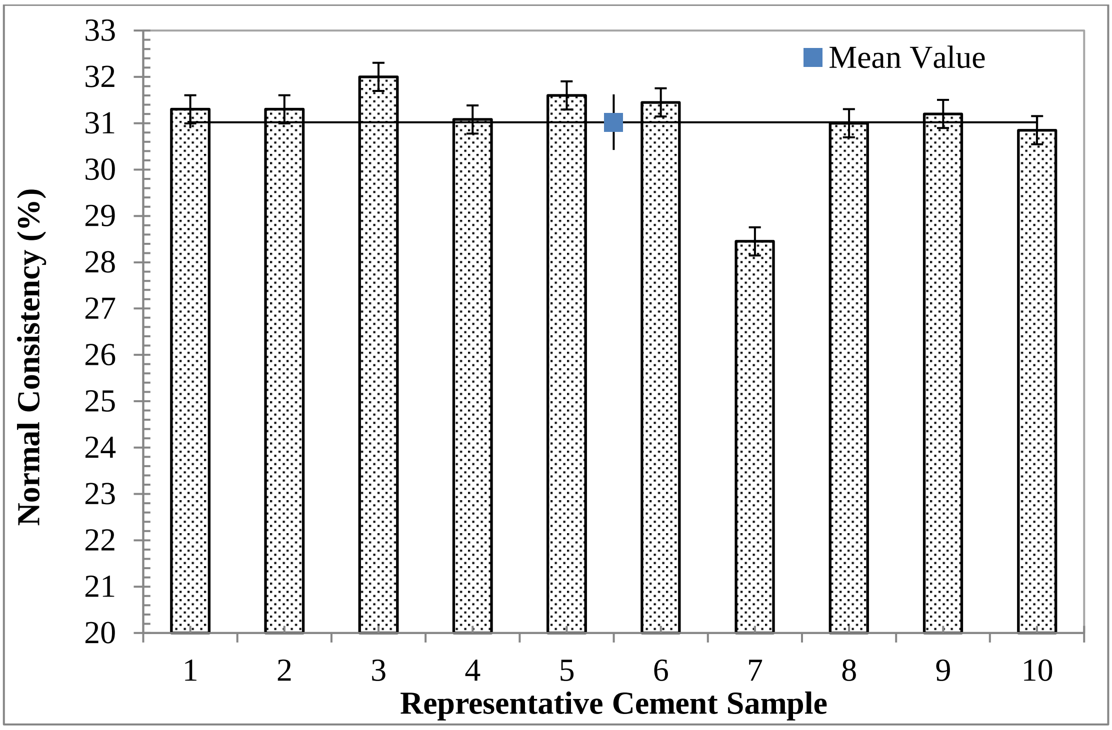



Figure 4.5: Normal consistency of representative cement samples

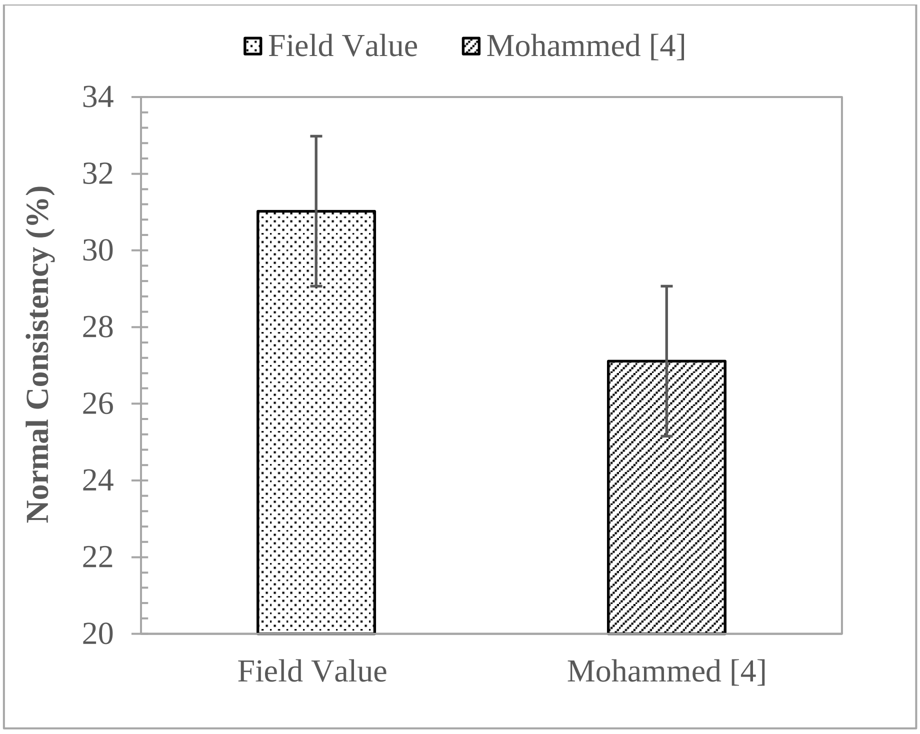



Figure 4.6: Comparison of normal consistency

### 4.5 Setting Time Test Results

Setting time test of cement samples were conducted as per ASTM C 191-04. The detail test procedure is presented in Chapter 3 Section 3.4.4. This section includes the experimental results of both initial setting time and final setting time. Initial setting time of cement may be estimated using the following formula:

$$\left(\frac{H-E}{C-D}\ x\ (C+25)\right)+E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.5)}$$

Where,

E = time in minutes of last penetration greater than 25 mm,

H = time in minutes of first penetration less than 25 mm,

C = penetration reading at time E and D = penetration reading time at time H.

**Figure 4.7** represents the variation of penetrations with setting time of representative cement samples (RCS) of 10 different manufacturer of Bangladesh. It is found that the setting of representative cement samples starts from 105 minutes. It is also observed from the results that minimum and maximum setting time are 120 minutes and 180 minutes, respectively at 25 mm penetration. Therefore, it can be realized that initial setting time of cement range may stay from 120 minutes to 180 minutes. The variation of initial setting time, final setting time and their mean values are shown in **Figure 4.8**. According to ASTM C 595-12, standard requirements of initial setting time should not be less than 45 minutes and final setting time is not more than 420 minutes. According to ASTM C 150, standard requirements of initial setting time is not less than 45 minutes and final setting time is not more than 375 minutes. Initial and final setting time of all representative cement samples are observed to be satisfactory as per ASTM requirements. Mean value of initial setting time is 155 minutes and 212 minutes for final setting time.

The average initial and final setting time of cement are compared with that of the previous study conducted by Mohammed **[4]** which is shown **Figure 4.9**. The figure shows that the average initial setting time of Bangladeshi cement is 33.62% higher than the initial setting time calculated by Mohammed **[4]**, but final setting time are found almost same in both studies.

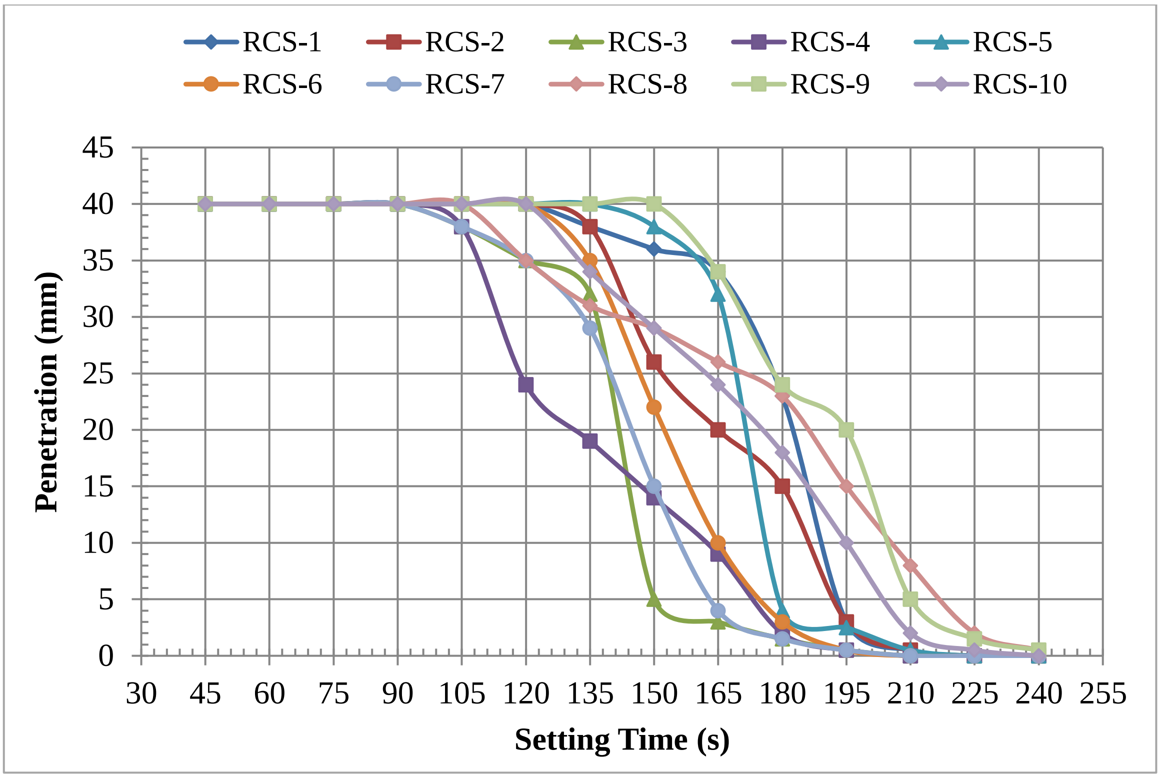



Figure 4.7: Setting time of representative cement samples

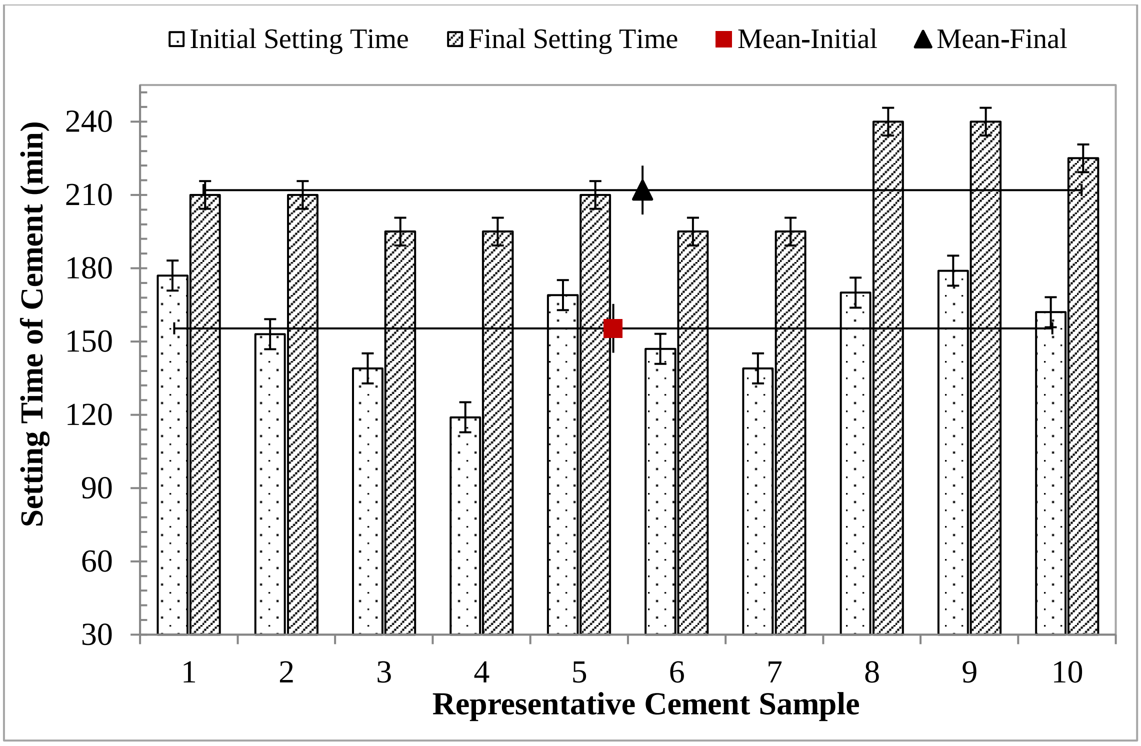
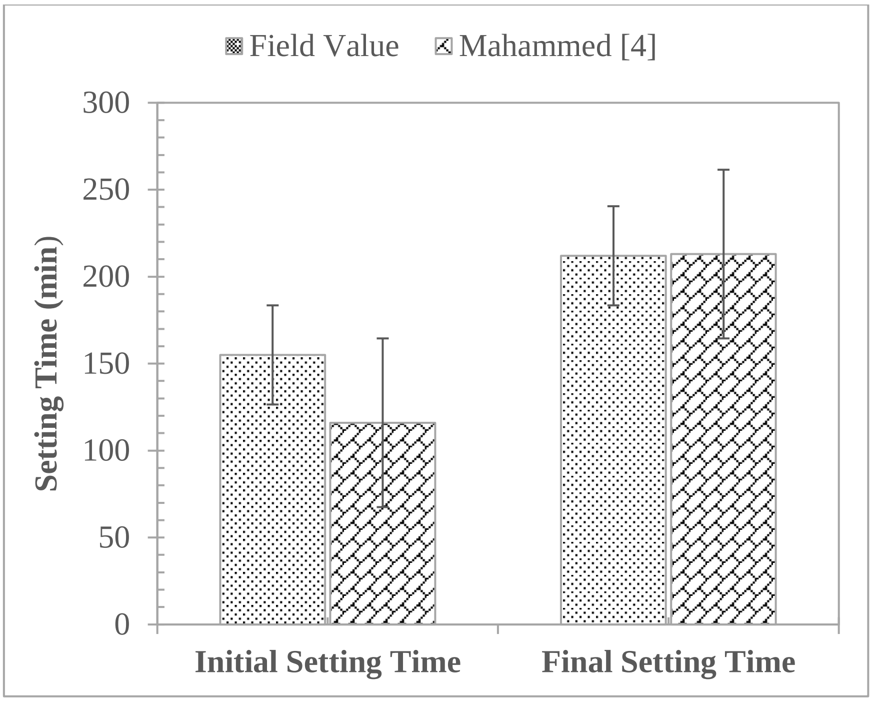
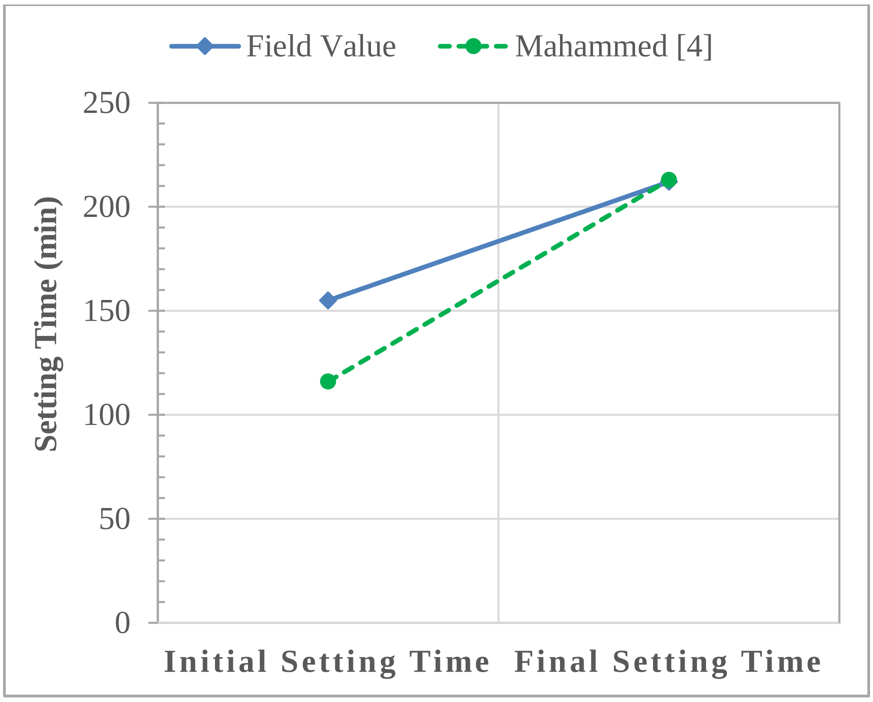



Figure 4.8: Initial and final setting time of representative cement samples




(a) Type-1: Initial and final setting time




(b) Type-2: Initial and final setting time

Figure 4.9: Comparison of initial setting time and final setting time with Mohammed [4]

### 4.6 Compressive Strength of Cement Mortars

Tests on compressive strength of cement mortar were conducted as per ASTM C 109-07. The detail test procedure is presented in Chapter 3 Section 3.4.5. The compressive strength of cement mortar made with different representative cement samples at 3, 7, and 28 days are presented on **Figure 4.10**. It can be seen that compressive strength of cement is increased with the age of the sample. According to ASTM C 595-12, standard requirements of compressive strength are 13 MPa (1890 psi) at 3 days, 20 MPa (2900 psi) at 7 days and 25 MPa (3620 psi) at 28 days. It is found that nine representative cement samples meet the 3-days requirement, 6 representative cement samples meet the 7-days requirement and 8 representative cement samples meet the 28-days requirement. The mean values of compressive strength are found to be 14.4 MPa (2080 psi) at 3-days, 20.2 MPa (2920 psi) for 7-days and 30.50 MPa (4430 psi) for 28-days which are presented on **Figure 4.10**.

The mean compressive strength of cement mortar made with different cements is compared with the previous study as shown in **Figure 4.11**. According to **Figure 4.11**, it is seen that all the mean compressive strengths obtained from current study at 3-days, 7-days and 28-days are higher than the result reported by Mohammed (2012). At age 3-days, 7-days and 28-days, the average compressive strengths of cement mortar are 12.96%, 21.98% and 35.60% greater than the results of Mohammed **[4]** respectively. This result highlights that the quality of Bangladeshi cement in terms of compressive strength improves significantly over the last decade.

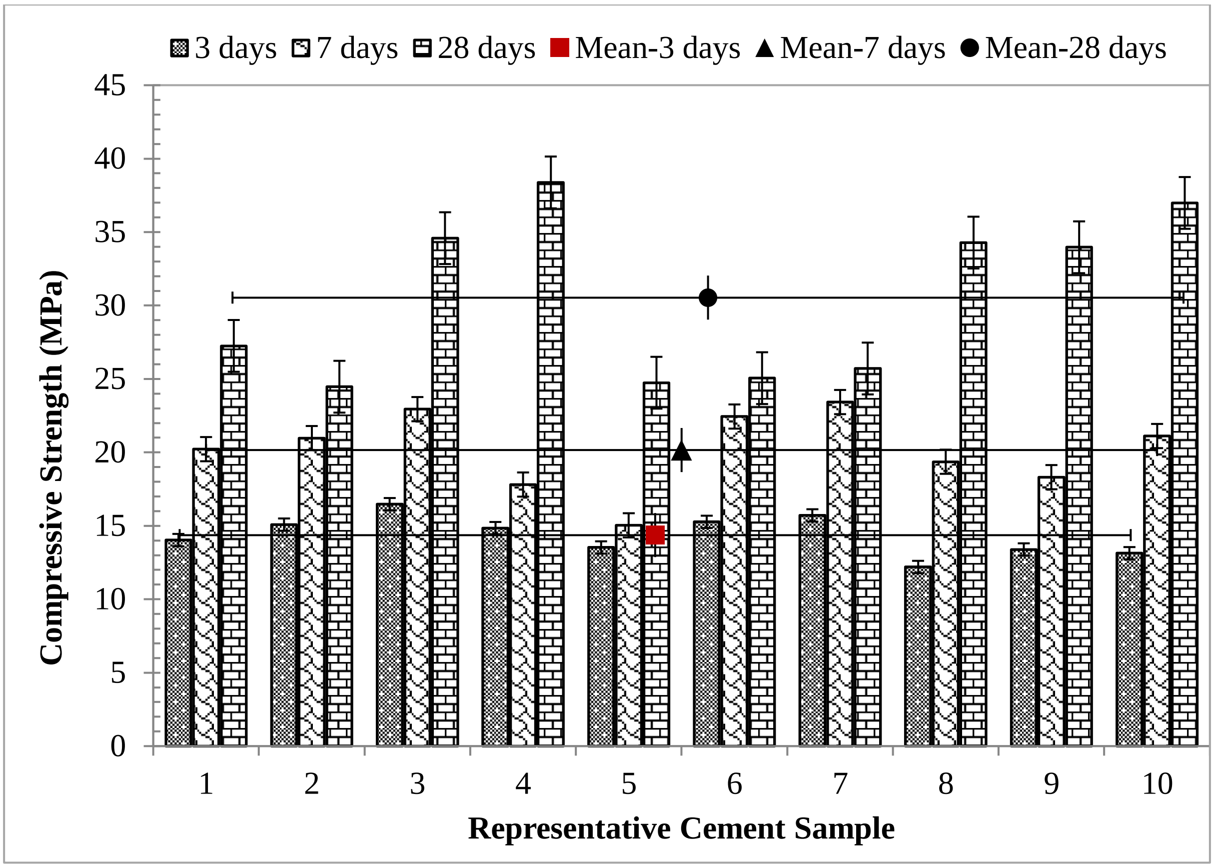
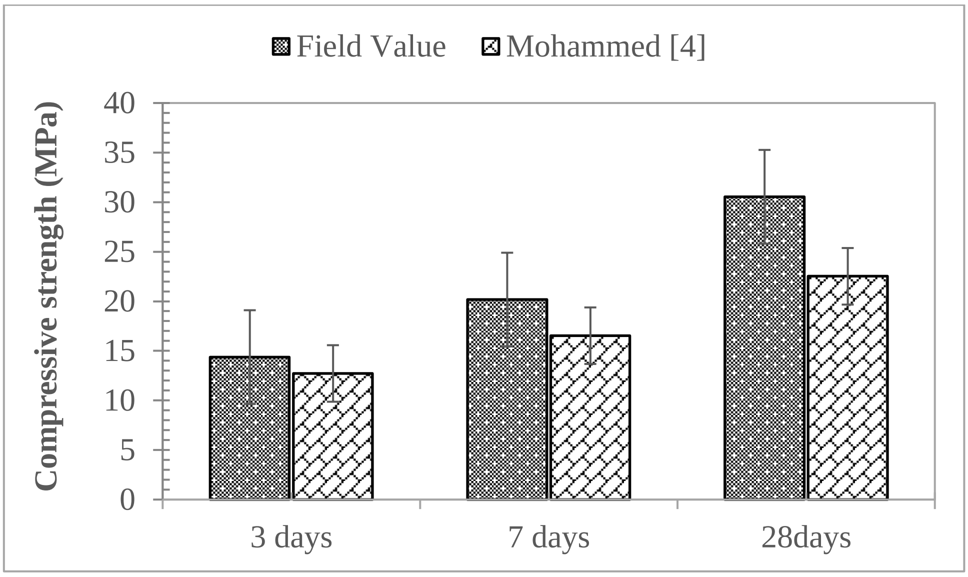
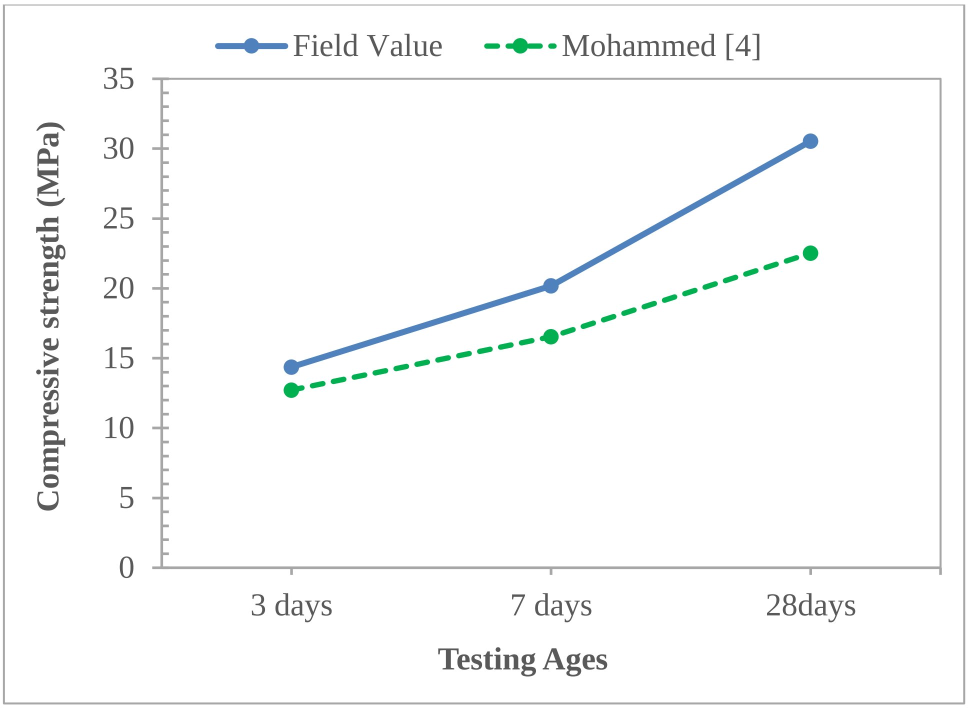



Figure 4.10: Variation of compressive strength with age (mortar)




(a) Type-1: Compressive strength with age




(b) Type-2: Compressive strength with age

Figure 4.11: Comparison of compressive strength with age

### 4.6.1 Regression analysis of compressive strength of cement mortar

Based on the experimental result obtained from this study, regression analysis is performed to obtain the 28 days compressive strength of mortar from the 3 day, 7 days and combined 3 days and 7 days compressive strength of mortar strength. In this study, the relationship between those compressive strengths are assumed as linear and hence linear regression analyses are performed. The equation for linear regression is; y = a + bx. The regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement mortar, the following relationship is obtained

$$f'_{c-28D} = 2.10 * f'_{c-3D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.6)}$$

Where

$f'_{c-28D}$ 28-day compressive strength of mortar

$f'_{c-3D}$ 3-day compressive strength of cement mortar

The coefficient of determination, $R^2$ is obtained as 0.956. It means, in this case 95.6% of the variation in y is explained by x and 4.4% is not explained. In this case, y-intercept a= 0 and slope b= 2.102. So from the regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement mortar, the following regression equation can be written. Regression relationship between 28-days and 3-days compressive strength of cement mortar is shown in **Figure 4.12**.

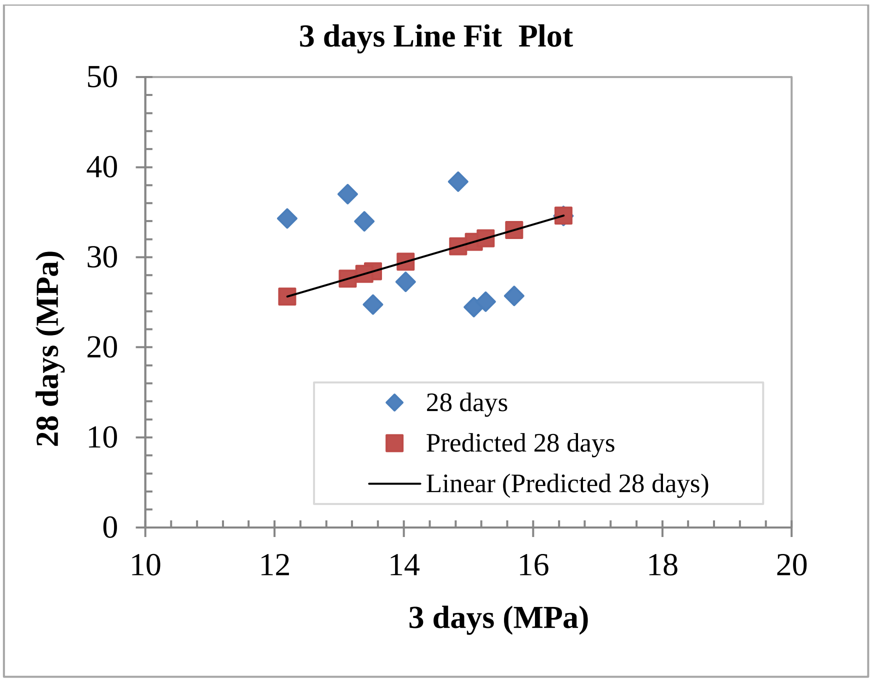



Figure 4.12: Regression relationship between 28-days and 3-days compressive strength of cement mortar

From the regression relationship between 28-days compressive strength of cement mortar and 7-days compressive strength of cement mortar it is observed that coefficient of determination, $R^2$ is 0.952. It means, in this case 95.2% of the variation in y is explained by x and 4.8% is not explained. In this case, y-intercept a= 0 and slope b= 1.48. Therefore, regression relationship between 28-days compressive strength of cement mortar and 7-days compressive strength of cement mortar, the following regression equation can be written. Regression relationship between 28-days and 7-days compressive strength of cement mortar is shown in **Figure 4.13**.

$$f'_{c-28D} = 1.49 * f'_{c-7D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.7)$$

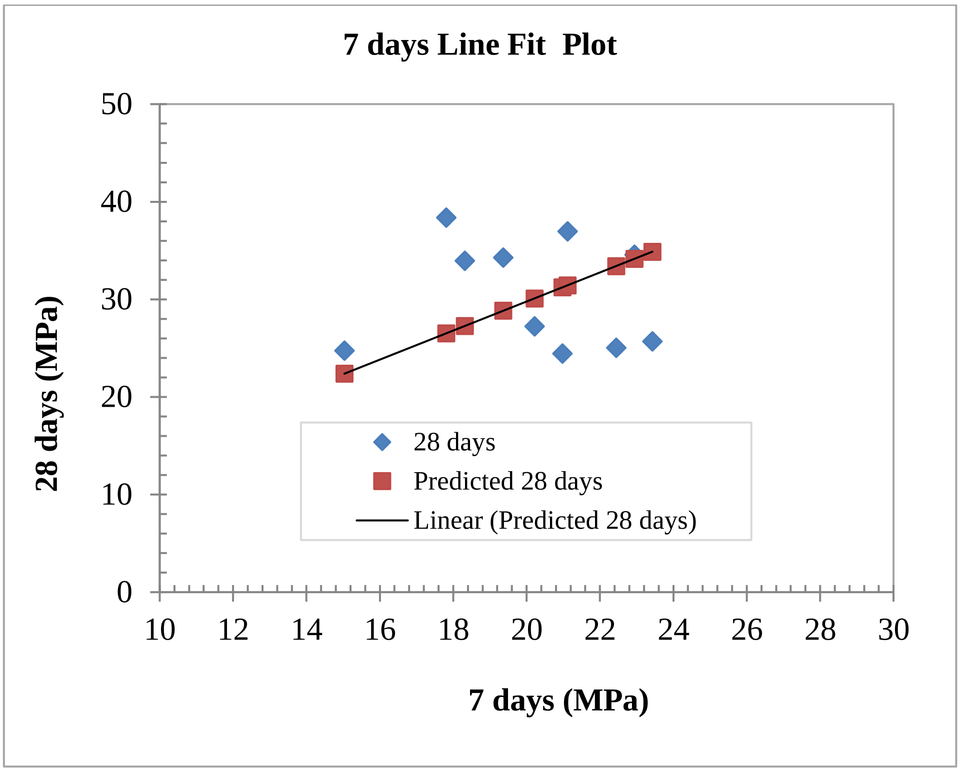



Figure 4.13: Regression relationship between 28-days and 7-days compressive strength of cement mortar

From the regression relationship among 28-days compressive strength of cement mortar and 3 and 7-days compressive strength of cement mortar it can be seen that adjusted $R^2$ is 0.826. Adjusted $R^2$ is used for multiple regression instead of $R^2$. In this case 82.6% of the variation in y is explained by x and 17.4% is not explained. In this case, y-intercept a= 0 and slope or coefficient for 3-days $b_1$= 1.489 and coefficient for 7-days $b_2$= 0.437. So from the regression relationship between 28-days compressive strength of cement mortar and 3 & 7-days compressive strength of cement mortar, the following regression equation can be written. Regression relationship among 28-days and 3 & 7-days compressive strength of cement mortar is shown in **Figure 4.14**.

$$f'_{c-28D} = 1.49 * f'_{c-3D} + 0.44 * f'_{c-7D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (4.8)$$

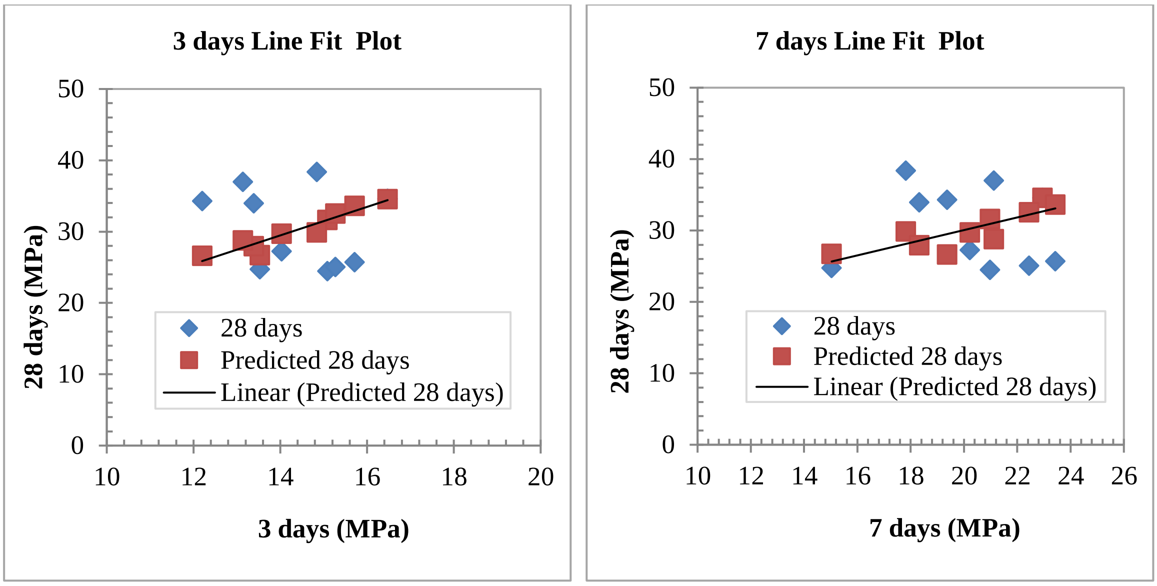



Figure 4.14: Regression relationship among 28-days and 3 & 7-days compressive strength of cement mortar

**Figure 4.15** represents the experimental results 28-days compressive strength of cement mortar and predicted 28 days compressive strength based on 3-days, 7-days and combination of 3 & 7-days compressive strength of cement mortar. The result shows a very good correlation between them. As discussed earlier, the 28 days mortar strength can be predicted quite accurately using the proposed equations.

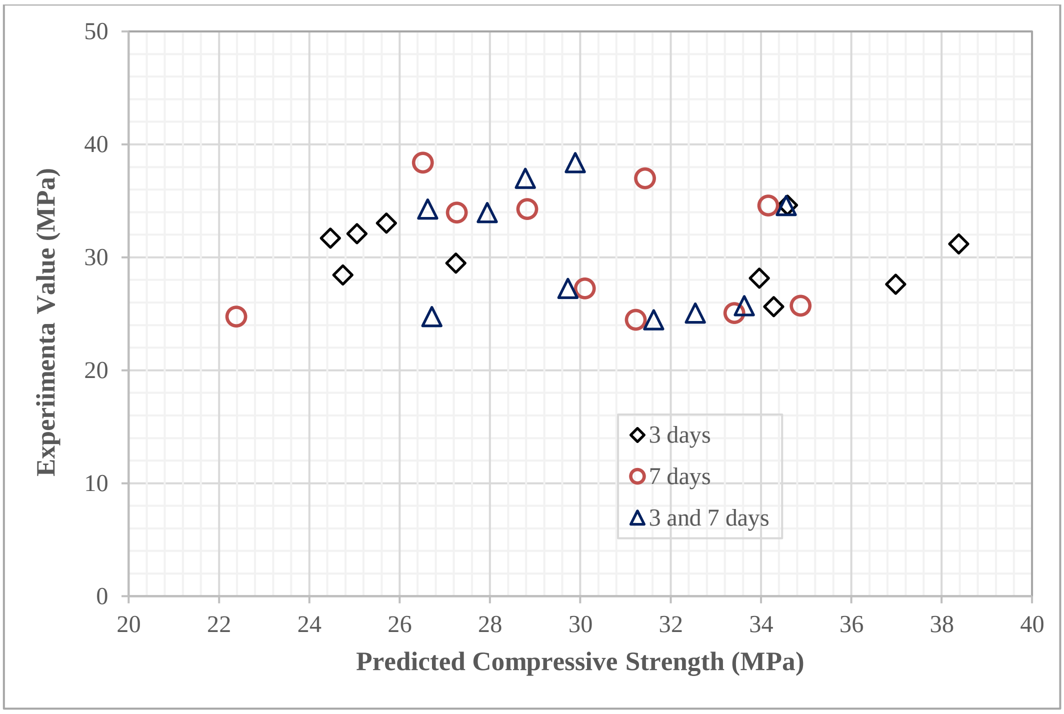
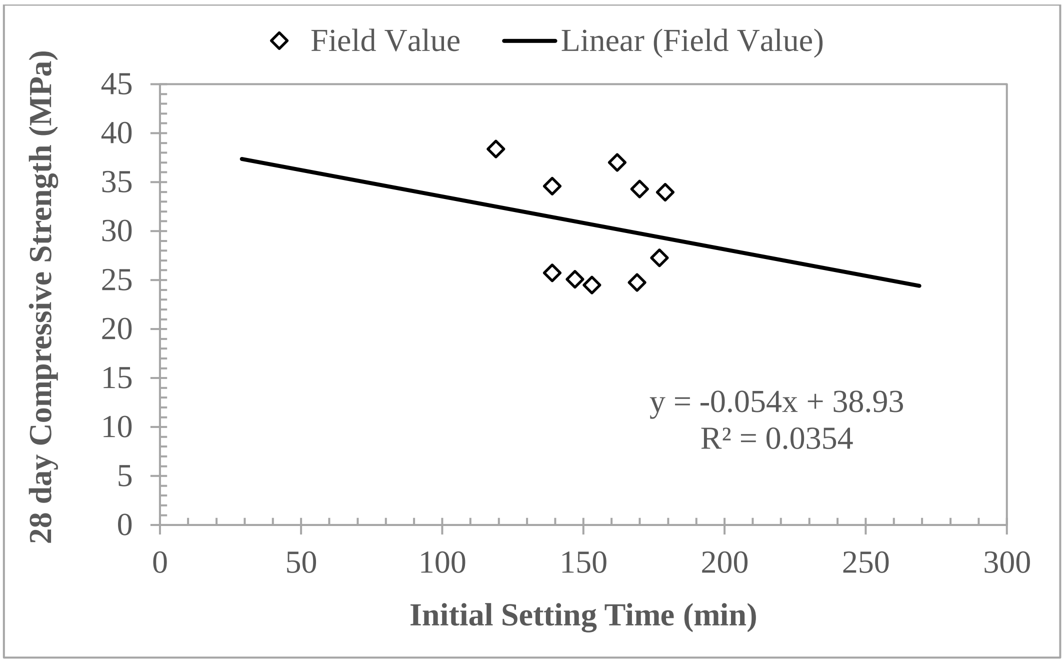



Figure 4.15: Experimental and predicted 28-days compressive strength of cement mortar

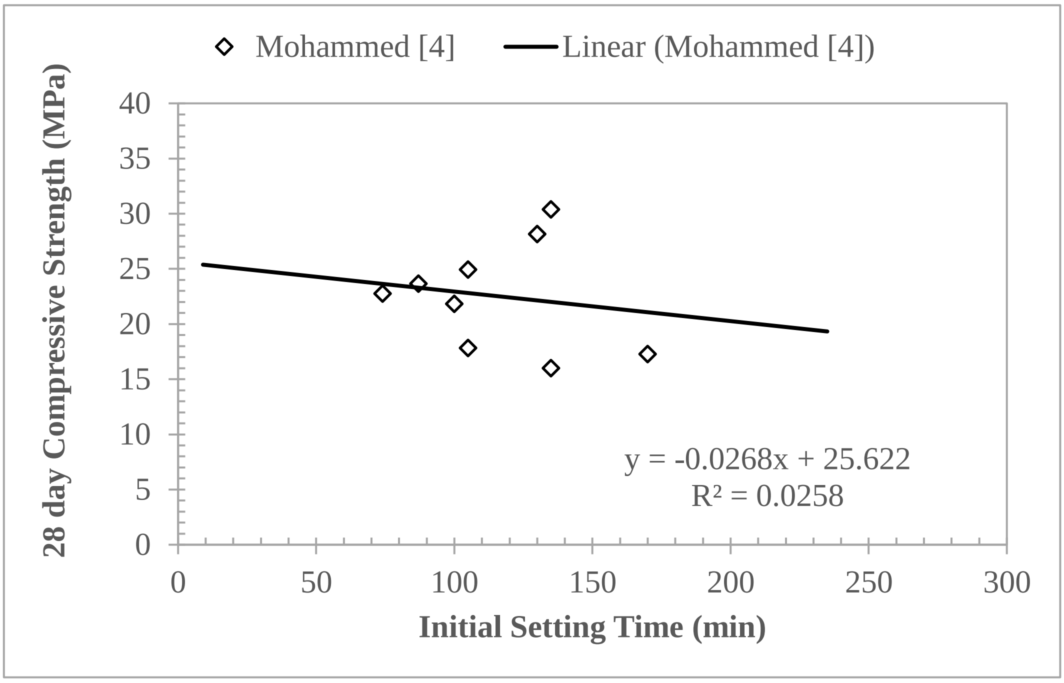
### 4.6.2 Variation of setting time and compressive strength of cement mortars

The variations of initial setting time with compressive strength of cement mortar are shown in **Figure 4.16(a)** and **Figure 4.16(b)**. According to **Figure 4.16(a)** and **Figure 4.16(b)**, it is found that there is a tendency of having lower level of strength for the cement with longer initial setting time. Hence, increasing tendency of compressive strength for the cement is 46% greater than the result of Mohammed **[4]** with initial setting time.

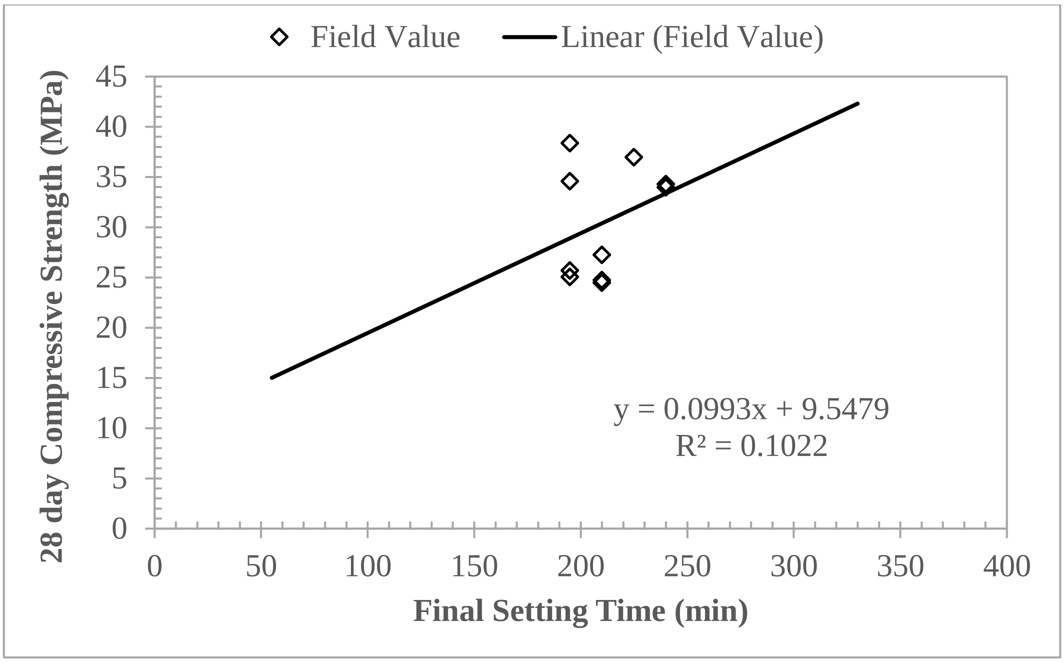
The variations of final setting time with compressive strength of cement mortar are shown in **Figure 4.16(c)** and **Figure 4.16(d).** According to **Figure 4.16(c)**, it is found that there is a tendency of having higher level of strength for the cement with longer final setting time, but **Figure 4.16(d)** shows that there is a tendency of having lower level of strength for the cement with longer final setting time. In spite of opposite tendency of having level, increasing tendency of compressive strength for the cement is 25% greater than the result of Mohammed **[4]** with final setting time. But correlations among initial setting time with compressive strength of cement mortar and final setting time with compressive strength of cement mortar are not good.



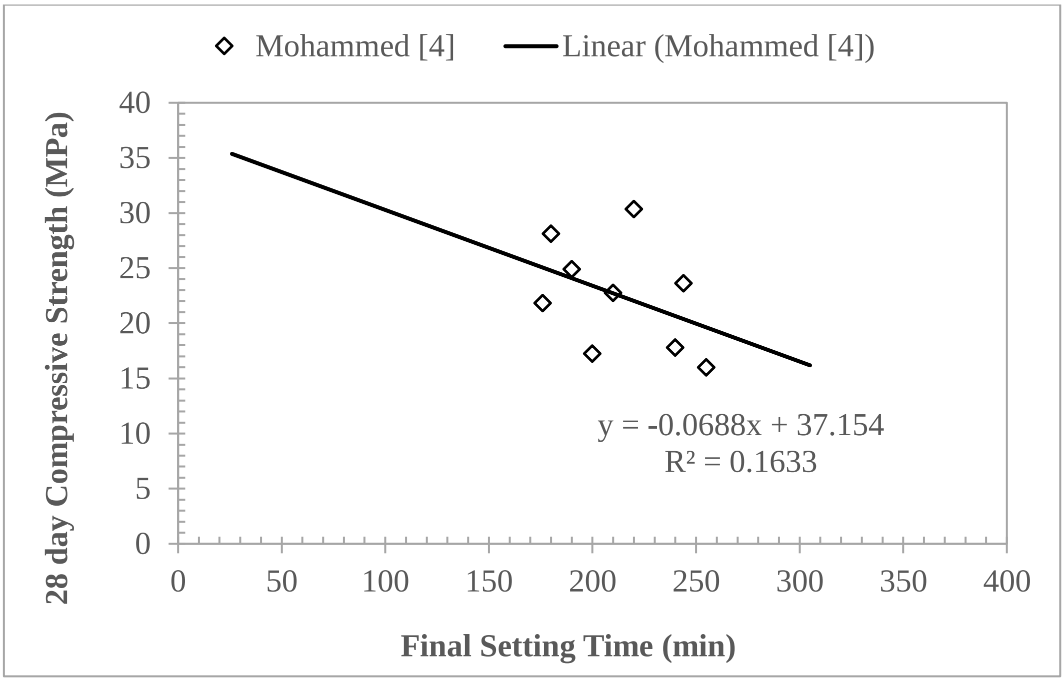

a) Initial setting time (Current Study)




b) Initial setting time [Mohammed **[4]**]




(c) Final setting time (Current Study)




(d) Final setting time [Mohammed **[4]**]

Figure 4.16: Variation of compressive strength with (a) initial setting time (Field Value), (b) initial setting time [Mohammed **[4]**], (c) final setting time (Field Value), (d) final setting time [Mohammed **[4]**]

### 4.6.3 Variation of fineness and compressive strength of cement mortars

Tests on compressive strength of cement mortar were conducted as per ASTM C 109-07. The detail test procedure is presented in Chapter 3 Section 3.4.5. This section of the results presents a relationship between fineness of cement and the compressive strength of cement mortar as shown in **Figure 4.17**. The rate of hydration depends on the fineness of cement particles. More the fineness of the cement is, more rapid is the development of strength of concrete. But it is observed from the figure that compressive strength of cement mortar is decreasing as the fineness of the cement increases. Correlations between the fineness and compressive strength of cement mortar are not good but correlations between the fineness and compressive strength of cement mortar can be used to predict the strength of cement from the fineness data that can be quickly determined in the laboratory.

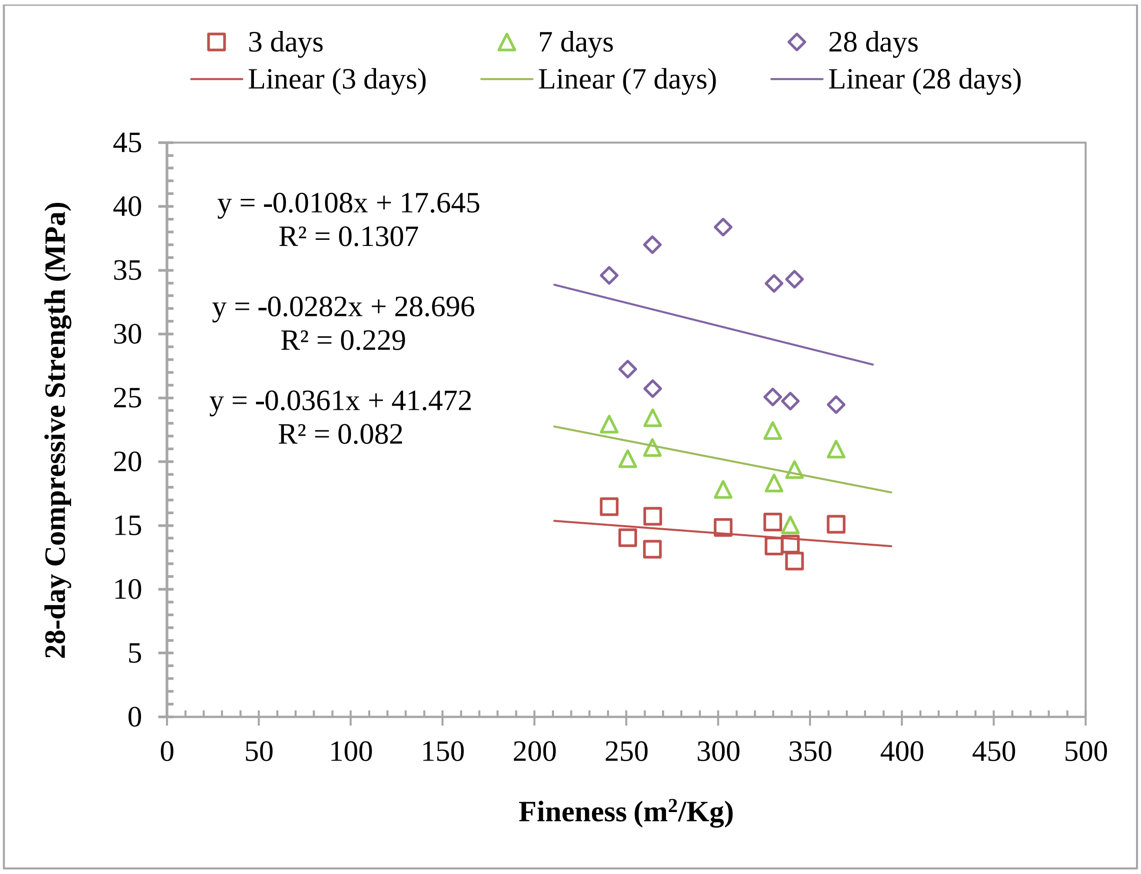



Figure 4.17: Variation of compressive strength (mortar) with fineness

### 4.7 Compressive Strength of Cylindrical Concrete Specimens

Tests on compressive strength of cylindrical concrete specimens were conducted as per ASTM C 39-04. The detail test procedure and test mechanism are presented in Chapter 3 Section 3.4.6. The variation of compressive strength of cylindrical concrete specimens is shown in **Figure 4.18**. Composition of mortars are- Cement: Sand: Coarse aggregate = 1: 1.5: 3 and Water–Cement ratio = 0.45. As per composition of mortar, 28-days compressive strength 24 MPa (3500 psi) is considered. According to the ASTM standard, the minimum strength to achieve at 3 days, 7 days, 14 days and 28 days are 40%, 65%, 90% and 99%, respectively. In view of that, minimum compressive strength at testing ages of 7 days, 14 days and 28 days are required to be 15.6 MPa (2275 psi), 21.6 MPa (3150) psi and 23.75 MPa (3465 psi), respectively. It is observed from the result that 8 representative cement samples meet the 7-days requirement, only 3 representative cement samples satisfy the 14-days requirement. However, all representative cement samples satisfy the 28-days ASTM requirement of strength. Mean value 17.07 MPa (2476 psi) for 7-days, mean value 20.82 MPa (3019 psi) for 14-days and mean value 36.51 MPa (5295 psi) for 28-days are shown in **Figure 4.18** also. It is important to highlight that the mean strength at 7-days, 14-days and 28-days are 70.74%, 86.26% and 151.28%, respectively.

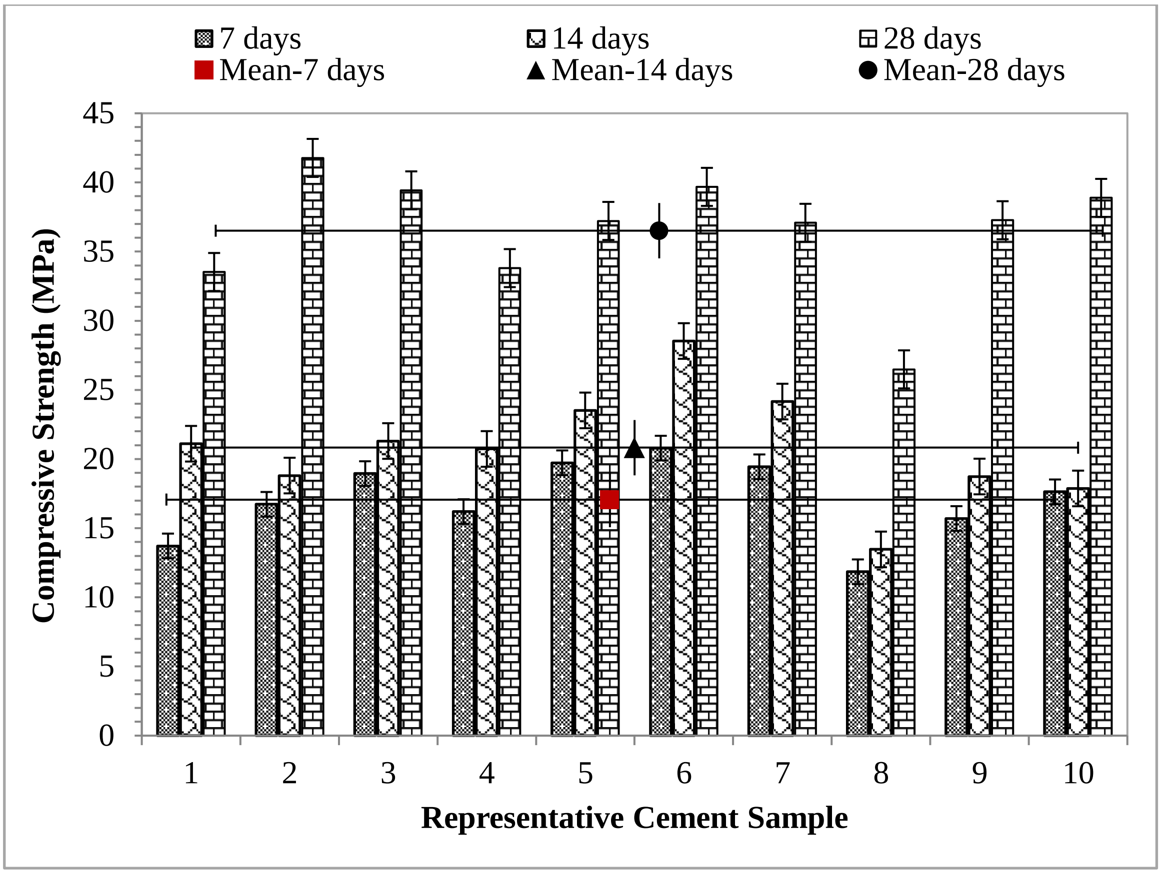



Figure 4.18: Variation of compressive strength with age (cylindrical)

### 4.7.1 Regression analysis of compressive strength of cylindrical concrete specimens

Based on the experimental result obtained for compressive strength of cylindrical concrete specimens, regression analysis is performed to obtain the 28 days compressive strength of concrete from the 7 day, 14 days and combined 7 day and14 day compressive strength of mortar strength. In this study, the relationship between those compressive strengths are assumed as linear and hence linear regression analyses are performed. The equation for linear regression is; y = a + bx.

The regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement cylinder the following relationship is obtained as

$$f'_{c-28D} = 2.12 * f'_{c-7D} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

Where

$f'_{c-28D}$ 28-day compressive strength of mortar

$f'_{c-7D}$ 7-day compressive strength of cement mortar

The coefficient of determination, $R^2$ is obtained as 0.99. It means, in this case 99% of the variation in y is explained by x and 1% is not explained. In this case, y-intercept a= 0 and slope b= 2.12. So from the regression relationship between 28-days compressive strength of concrete cylinders and 7-days compressive strength of cylinders, the above stated regression equation can be written. Regression relationship between 28-days and 7-days compressive strength of cement mortar is shown in **Figure 4.19**.

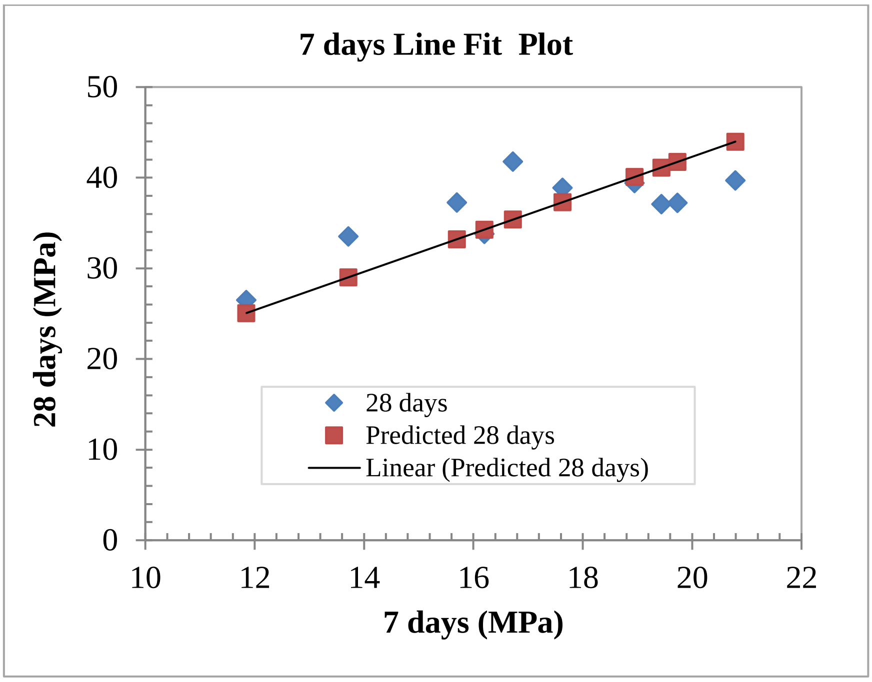



Figure 4.19: Regression relationship between 28-days and 7-days compressive strength of cylindrical concrete specimens

From the regression relationship between 28-days compressive strength of cylindrical concrete specimens and 14-days compressive strength of cylindrical concrete specimens it can be seen that coefficient of determination, $R^2$ is 0.976. It means, in this case 97.6% of the variation in y is explained by x and 2.4% is not explained. In this case, y-intercept a=

0 and slope b= 1.7138. So from the regression relationship between 28-days compressive strength of cylindrical concrete specimens and 14-days compressive strength of cylindrical concrete specimens, the following regression equation can be written. Regression relationship between 28-days and 14-days compressive strength of cylindrical concrete specimens is shown in **Figure 4.20**.

$$f'_{c-28D} = 1.71 * f'_{c-14D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.10)}$$

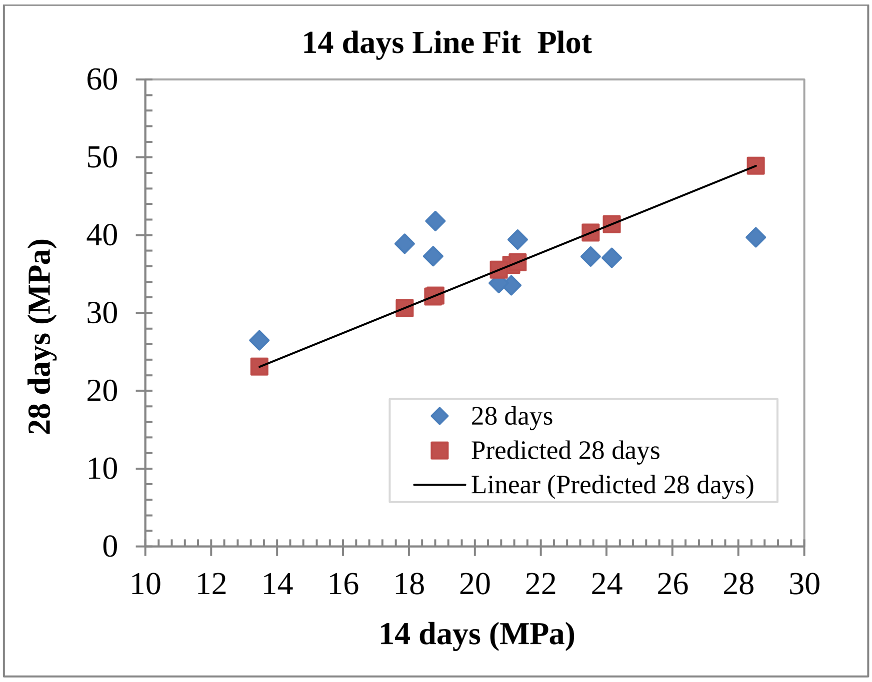



Figure 4.20: Regression relationship between 28-days and 14-days compressive strength of cylindrical concrete specimens

From the regression relationship among 28-days compressive strength of cylindrical concrete specimens and 7 & 14-days compressive strength of cylindrical concrete specimens it can be seen that adjusted $R^2$ is 0.864. Adjusted $R^2$ is used for multiple regression instead of $R^2$. In this case 86.4% of the variation in y is explained by x and 13.6% is not explained. In this case, y-intercept a= 0 and slope or coefficient for 7-days $b_1$= 2.392 and coefficient for 14-days $b_2$= -0.227. So from the regression relationship between 28-days compressive strength of cylindrical concrete specimens and 7 & 14-days compressive strength of cylindrical concrete specimens, the following regression equation can be written. Regression relationship among 28-days and 7 & 14-days compressive strength of cylindrical concrete specimens is shown in **Figure 4.21**.

$$f'_{c-28D} = 2.39 * f'_{c-7D} - 0.23 * f'_{c-14D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

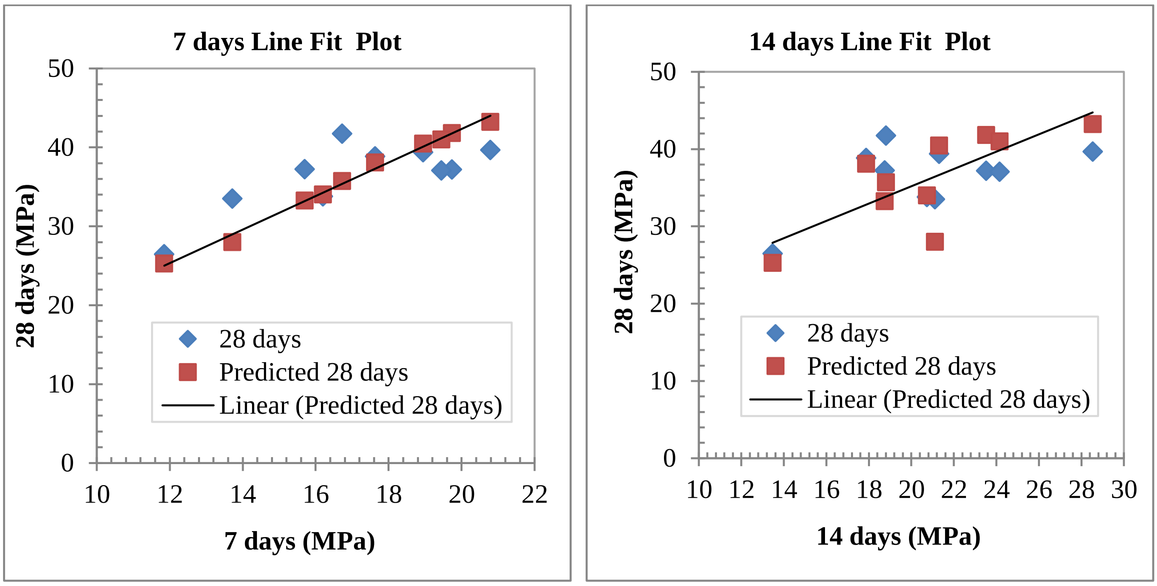



Figure 4.21: Regression relationship among 28-days and 7 & 14-days compressive strength of cylindrical concrete specimens

**Figure 4.22** represents the predicted 28-days compressive strength of cylindrical concrete specimens against 7-days, 14-days and combination of 7 & 14-days compressive strength of cylindrical concrete specimens. From the regression relationship among fc 28 days and fc 7 days, fc 28 days and fc 14 days and fc 28 days and fc 7 & 14 days, it is possible to predict 28-days compressive strength quite accurately.

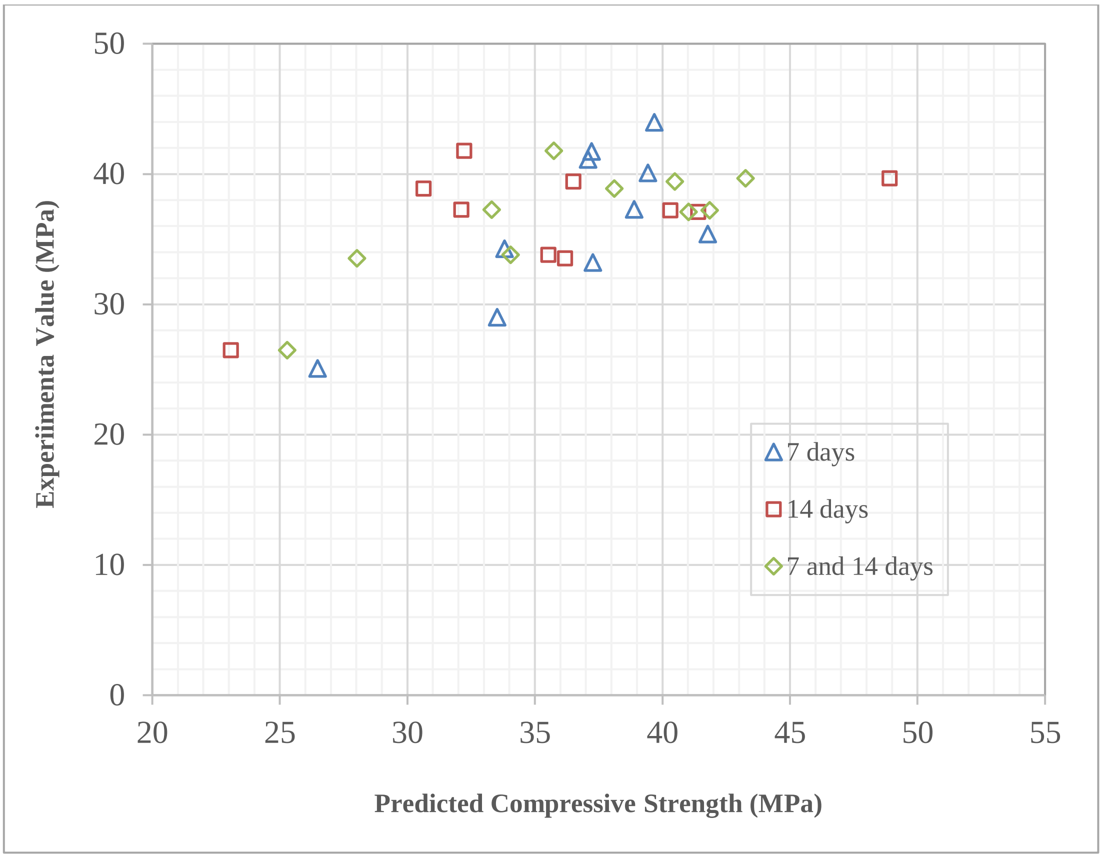



Figure 4.22: Experimental and predicted 28-days compressive strength of cylindrical concrete specimens

### 4.7.2 Variation of fineness and compressive strength (cylindrical)

The variations of fineness with compressive strength of cylindrical concrete specimens is shown in **Figure 4.23**. It is found that there is a tendency of having lower level of compressive strength for the cement with longer fineness for compressive strength of cylindrical concrete specimens. Correlations between the fineness and compressive strength of cylindrical concrete specimens are not good but correlations between the fineness and compressive strength of cylindrical concrete specimens can be used to predict the strength of cement from the fineness data that can be quickly determined in the laboratory.

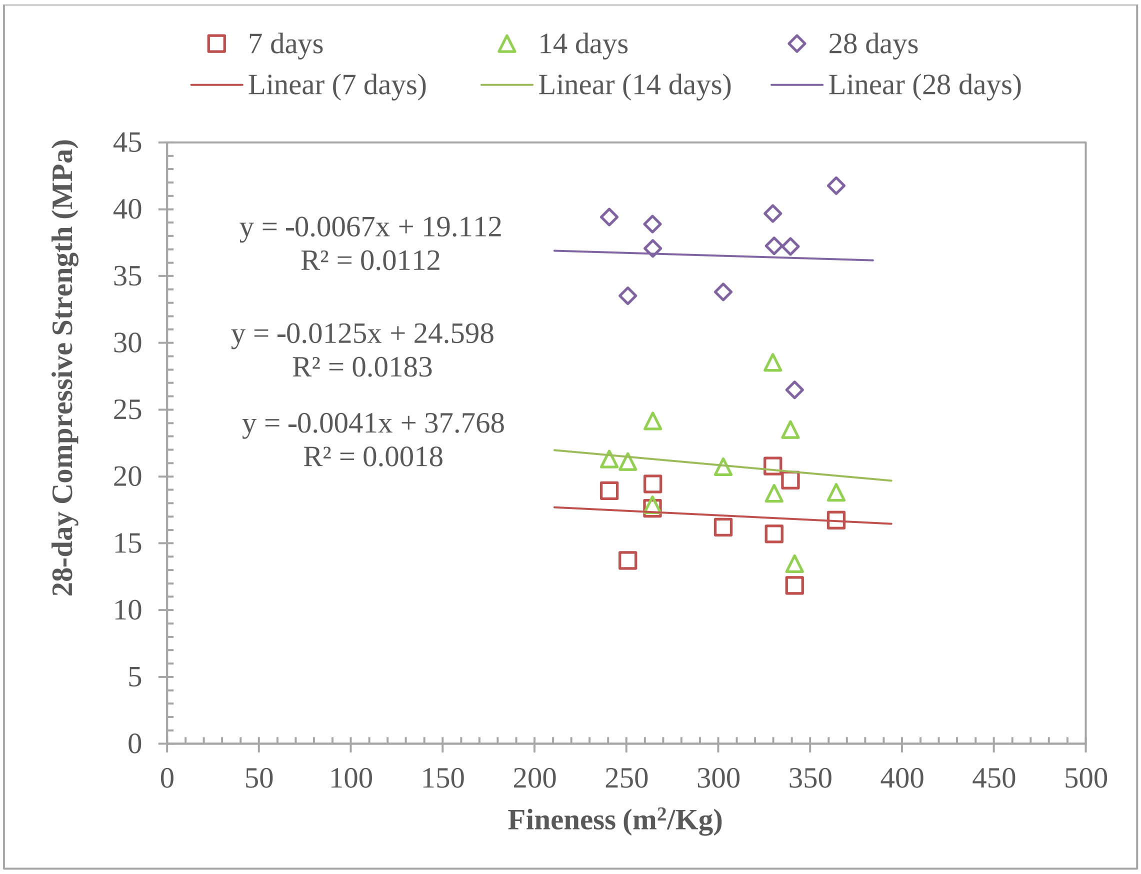



Figure 4.23: Variation of compressive strength (cylindrical) with fineness

### 4.8 Comparison of compressive strength between mortar and cylindrical

A comparison between the compressive strength of cement mortar and compressive strength of cylindrical concrete specimens with age is shown in **Figure 4.24**. It is found that all (except one) compressive strength of cement mortar is higher than the cylindrical compressive strength with age 7 days. On the other hand, all (except two) compressive strength of cement mortar is lower than the compressive strength of concrete cylinders with age 28 days. **Figure 4.24** represents the mean value 20.2 MPa (2920 psi) for 7-days (mortar), 17 MPa (2476 psi) for 7-days (cylindrical), 30.50 MPa (4430 psi) for 28-days (mortar) and 36.50 MPa (5300 psi) for 28-days (cylindrical). It is found that the mean value of compressive strength for 7-days (mortar) is 18.10% higher than the compressive strength for 7-days (cylindrical) and the mean value of compressive strength for 28-days (mortar) is 19.55% lower than the compressive strength for 28-days (cylindrical).

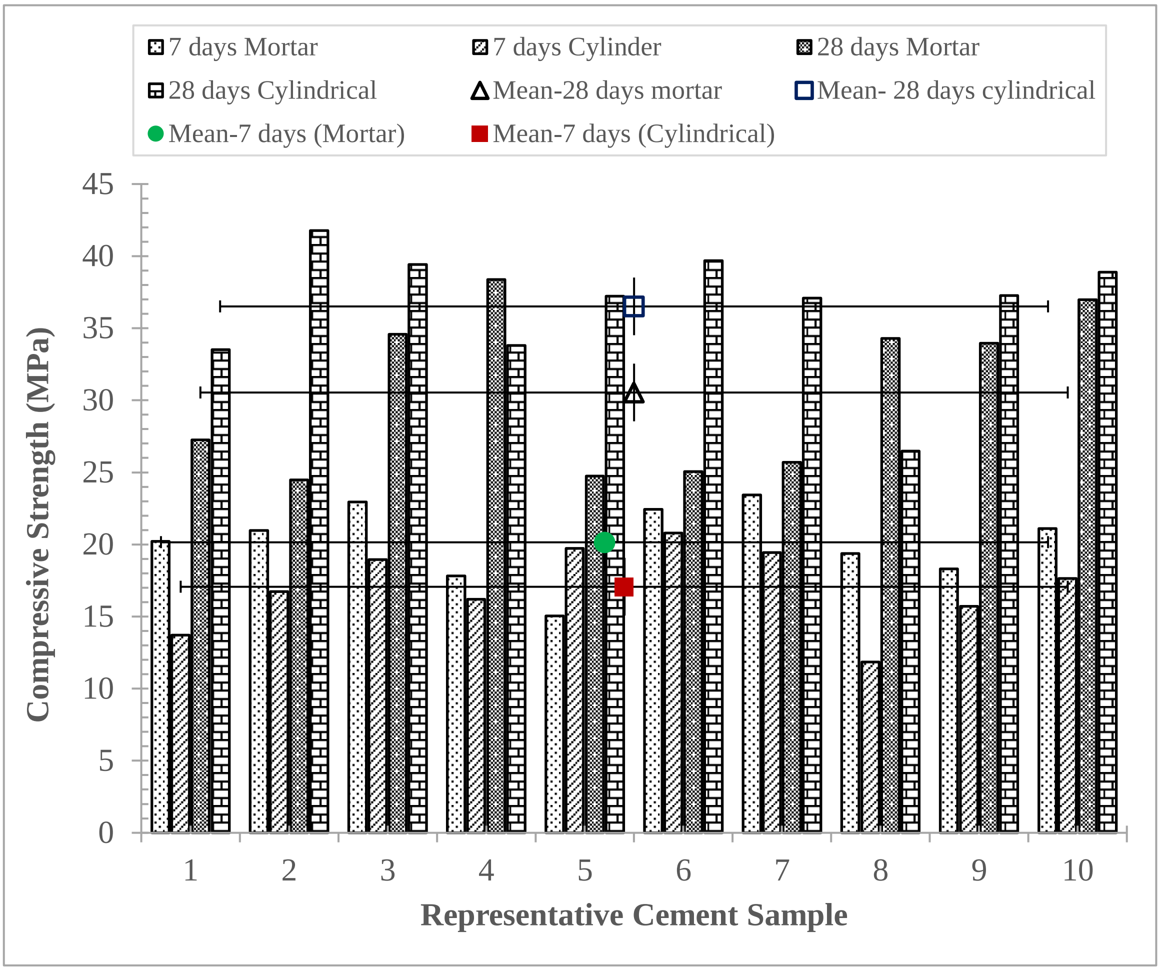



Figure 4.24: Variation of compressive strength with age (mortar & cylindrical)

### 4.9 Summary of Findings

In this study, a total 300 numbers of representative Bangladeshi cement samples are tested to obtain the physical properties. The test results provide an overview of quality of Bangladeshi cements. In addition, Regression analysis are conducted using the tested results. This study also provides the relationship between compressive strength at different ages, between mortar and cylinder strength, fineness and compressive strengths. Moreover, the results are compared with existing study in some cases. The key findings from this study can be summarised as follows:

i) The experimental results on density and specific gravity showed that the mean density of all tested samples is 3.023 whereas the ASTM range of specific gravity of such type cements varies in the range of 3.12-3.19. Since the mean value is very close to ASTM range, it can be concluded that specific gravity of Bangladeshi cements follows the guideline quite accurately.

ii) The experimental result showed that fineness of more than 80% of the tested cement samples are in the AASTM guideline range (260-430) $m^2$/kg). The mean value of fineness of all the samples is 303 $m^2$/kg that satisfies the ASTM standards. Therefore, cements manufactures in Bangladesh showed a good agreement with the ASTM guideline that illustrates the quality of cements as far as fineness's concern.

iii) According to the ASTM C 187, normal consistency of cement is 22~30%. However, it interesting to note that the Bangladeshi cements showed a bit higher consistency than the ASTM range. 90% of the representative cement samples showed quite similar behavior. Consistency of those samples just higher than the ASTM guideline. All the samples showed consistency in the range of 28.0~32% rather (22-30%) with a mean value of normal consistency is 31 %.

iv) All representative cement samples satisfy the ASTM C 595-12 requirements of the limit of initial setting time and final setting time. The mean values of both initial and final setting time are also in the range. It is found that there is a tendency of achieving lower strength for the representative cement samples with longer initial setting time and higher level of strength for the cement with longer final setting time.

v) The result showed that compressive strength of cement increases with age as expected. According to ASTM C 595-12, standard requirements of compressive strength of cement mortars are 13 MPa (1890 psi) in 3 days, 20 MPa (2900 psi) in 7 days and 25 MPa (3620 psi) in 28 days. It is found that 90% representative cement samples satisfy the 3-days requirement, 60% representative cement samples satisfy the 7-days requirement and 80% representative cement samples satisfy the 28-days requirement. Mean values of compressive strength at different age satisfy the ASTM requirements.

vi) According to the ASTM standard of compressive strength of cylindrical concrete specimens, the minimum rates of strength gaining are 3 days 40%, 7 days 65%, 14 days 90% and 28 days 99%. The mean value 17 MPa (2480 psi) for 7-days, mean value 20.8 MPa (3020 psi) for 14-days and mean value 36.5 MPa (5300 psi) for 28-days. It is seen that the average strength gaining rate 70.74% for 7-days, 86.26% for 14-days and 151.28% for 28-days.

vii) It is found that all (except one) compressive strength of cement mortar is higher than the cylindrical compressive strength with age 7 days. On the other hand, compressive strength of all except two cement mortar samples are lower than the cylindrical compressive strength with age 28 days. It can be seen that there is a tendency of having lower level of compressive strength for the cement with longer fineness for both mortar and cylindrical. Satisfaction of ASTM requirements of all test outputs is better than the results of Mohammed [4].

viii) In addition to the experimental results regression analysis has been performed to obtain closed form solutions for concrete compressive strength at different ages as presented on Eqs 4.6 to 4.11. The relation shows a god agreement with the experimental results with determination coefficient over 0.8 in all cases.

# CHAPTER - 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

In Bangladesh, due to the huge construction works, the demand of cement is increasing day by day. A number of industries produces cements not only to meet the local demand but also export cement all over the world. At this stage, the quality of Bangladeshi cement has become a burning issue for quality construction and sustainable development of the local market and increasing the national revenue by exporting a large part of cement production.

The main objective of this research was to assess physical qualities of cements of Bangladesh using experimental investigations. In order to determine the physical properties cement such as normal consistency, initial and final setting time, compressive strength of cement mortars, compressive strength (cylindrical), density, specific gravity and fineness of cement, standard tests were performed on cements manufactured by ten different industries of Bangladesh. A total 300 tests samples on CEM II/B-M type representative cement samples were prepared to conduct tests on those physical parameters as per ASTM specifications.

The experimental results obtained from this study are also analyzed to investigate the statistical parameters. The results are compared with the ASTM guideline values and previous available study. In addition, correlations are also developed to find relationships between compressive strength of concrete and their age of curing. The influence of initial and final setting times on concrete strength are also investigated. The relationship between mortar strength and concrete strength from the same batch of cement are also investigated.

In addition, Regression analysis are conducted using the tested results. This study also provides the relationship between compressive strength at different ages, between mortar and cylinder strength, fineness and compressive strengths. Moreover, the results are compared with existing study in some cases.  The key findings from this study can be summarised as follows:

1. The experimental results on the density and specific gravity of all representative cement samples are very close and the differences among the densities and specific gravities are very low. The density of cement varies in range 2.91 to 3.15 gm/cm$^3$ with a mean density of 3.023 gm/cm$^3$. Only one out of ten industries shows a density below 3.0 gm/cm$^3$ (RCS-3) which is only 10% of the total cement samples. The range is also very close to the ASTM standard value of 3.15 gm/cm$^3$. Therefore, it can be concluded that the density of Bangladeshi cement shows a standard following ASTM guideline.
2. The experimental result showed that fineness of more than 80% of the tested cement samples are in the AASTM guideline range (260-430) m$^2$/kg). It is found that fineness of two representative cement samples falls below the ASTM range. However, their values are also close to the lower range of ASTM C 150 requirements. The mean value of fineness of all the samples is 303 m$^2$/kg that satisfies the ASTM standards.
3. According to the ASTM C 187, normal consistency of cement is 22~30%. However, it interesting to note that the Bangladeshi cements showed a bit higher consistency than the ASTM range. 90% of the representative cement samples showed quite similar behavior. Consistency of those samples just higher than the ASTM guideline. All the samples showed consistency in the range of 28.0~32% rather (22-30%) with a mean value of normal consistency is 31 %.

4. All representative cement samples satisfy the ASTM C 595-12 requirements of the limit of initial setting time and final setting time. The mean values of both initial and final setting time are also in the range. It is found that there is a tendency of achieving lower strength for the representative cement samples with longer initial setting time and higher level of strength for the cement with longer final setting time.
5. The result showed that compressive strength of cement increases with age as expected. According to ASTM C 595-12, standard requirements of compressive strength of cement mortars are 13 MPa (1890 psi) in 3 days, 20 MPa (2900 psi) in 7 days and 25 MPa (3620 psi) in 28 days. It is found that 90% representative cement samples satisfy the 3-days requirement, 60% representative cement samples satisfy the 7-days requirement and 80% representative cement samples satisfy the 28-days requirement. Mean values of compressive strength of all representative cement samples at different ages satisfy the ASTM requirements.
6. According to the ASTM standard of compressive strength of cylindrical concrete specimens, the minimum rates of strength gaining are 3 days 40%, 7 days 65%, 14 days 90% and 28 days 99%. The mean value 17 MPa (2480 psi) for 7-days, mean value 20.80 MPa (3020 psi) for 14-days and mean value 36.5 MPa (5300 psi) for 28-days. It is seen that the average strength gaining rate 70.74% for 7-days, 86.26% for 14-days and 151.28% for 28-days.
7. It is found that all (except one) compressive strength of cement mortar is higher than the cylindrical compressive strength with age 7 days. On the other hand, compressive strength of all except two cement mortar samples are lower than the cylindrical compressive strength with age 28 days. It can be seen that there is a

tendency of having lower level of compressive strength for the cement with longer fineness for both mortar and cylindrical.

8. Based on the experimental result, regression analysis has been performed to develop closed form solutions for concrete compressive strength at different ages.

   i) The regression relationship between 28-days compressive strength of cement mortar and 3-days compressive strength of cement mortar, the following relationship is obtained as follows $f'_{c-28D} = 2.10 * f'_{c-3D}$.

   The coefficient of determination of the relationship is $R^2 = 0.956$.

   ii) Regression relationship between 28-days and 7-days compressive strength of cement mortar is obtained as follows $f'_{c-28D} = 1.49 * f'_{c-7D}$.

   The coefficient of determination of the relationship is $R^2 = 0.952$.

   iii) The regression relationship between 28-days compressive strength of cement cylinder and 7-days compressive strength of cylindrical concrete specimens is obtained as follows $f'_{c-28D} = 2.12 * f'_{c-7D}$.

   The coefficient of determination of the relationship is $R^2 = 0.99$.

   iv) Regression relationship between 28-days and 14-days compressive strength of cylindrical concrete specimens is found as $f'_{c-28D} = 1.71 * f'_{c-14D}$.

   The coefficient of determination of the relationship, $R^2 = 0.976$.

## 5.2 Limitations of this Study

The study has the following limitations:

1. This research program could not include the chemical composition and soundness test of cements which could improve the content of the research. However, the apparatus for those tests are still not only difficult to avail but also expensive.
2. Source of cement ingredients all brands are still unknown since the manufacturer did not cooperate to provide such information.

## 5.3 Recommendations for the Future Studies

1. In the present study, experimental investigations are performed for CEM II/B-M type cements. In addition, cements samples from ten different manufacturers are considered as the representative cements. As further study, it is recommended to study for CEM II/B-M, CEM II/A-M, CEM II/A-S and CEM II/A-L type cements with more numbers representative cements.
2. Due to limitations, this study did not consider the chemical composition tests and soundness test of the cement samples. In future study, chemical composition test may be conducted by SEM or XRD. In addition, soundness of cement may be tested to learn the physical properties of cement in wide range.

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# APPENDICES

## Appendix A: Density Test Results of Representative Cement Samples

Table A1: Density test results of representative cement samples

| Representative Cement Sample | Weight of Cement (gm) | Initial Reading (mm) | Final Reading (mm) | Ave. Final Reading (mm) | Density ($gm/cm^3$) |
|---|---|---|---|---|---|
| RCS-1 | 64<br>64 | 0.5<br>0.5 | 21.78<br>21.82 | 21.8 | 3 |
| RCS-2 | 64<br>64 | 0.5<br>0.5 | 21.19<br>21.21 | 21.2 | 3.09 |
| RCS-3 | 64<br>64 | 0.5<br>0.5 | 22.5<br>22.5 | 22.5 | 2.91 |
| RCS-4 | 64<br>64 | 0.5<br>0.5 | 20.75<br>20.85 | 20.8 | 3.15 |
| RCS-5 | 64<br>64 | 0.5<br>0.5 | 21.9<br>21.9 | 21.9 | 3.00 |
| RCS-6 | 64<br>64 | 0.5<br>0.5 | 21.17<br>21.23 | 21.2 | 3.09 |
| RCS-7 | 64<br>64 | 0.5<br>0.5 | 21.8<br>21.8 | 21.8 | 3 |
| RCS-8 | 64<br>64 | 0.5<br>0.5 | 21.65<br>21.55 | 21.6 | 3.03 |
| RCS-9 | 64<br>64 | 0.5<br>0.5 | 21.8<br>21.8 | 21.8 | 3 |
| RCS-10 | 64<br>64 | 0.5<br>0.5 | 21.38<br>21.42 | 21.4 | 3.06 |

## Appendix B: Fineness Test Results of Representative Cement Sample

Table B1: Permeability test results of representative cement samples

| Representative Cement Sample | Weight of Cement (gm) | Time (s) | | | Ave. Time (s) | Specific Gravity | Porosity (ϵ) | Fineness ($m^2/Kg$) |
|---|---|---|---|---|---|---|---|---|
| | | $T_1$ | $T_2$ | $T_3$ | | | | |
| RCS-1 | 2.71 | 43.43 | 43.47 | 43.58 | 43.49 | 3 | 0.5 | 251 |
| RCS-2 | 2.75 | 77.11 | 78.55 | 78.65 | 78.10 | 3.09 | 0.508 | 364 |
| RCS-3 | 2.7 | 43.1 | 43.53 | 43.88 | 43.50 | 2.91 | 0.487 | 241 |
| RCS-4 | 2.75 | 55.15 | 56.74 | 56.79 | 56.23 | 3.15 | 0.52 | 303 |
| RCS-5 | 2.66 | 70.33 | 72.08 | 71.8 | 71.40 | 3 | 0.51 | 339 |
| RCS-6 | 2.75 | 70.07 | 74.32 | 70.42 | 71.60 | 3.09 | 0.51 | 330 |
| RCS-7 | 2.71 | 38.88 | 52.43 | 53.79 | 48.37 | 3 | 0.5 | 264 |
| RCS-8 | 2.7 | 79.12 | 67.42 | 75.01 | 73.85 | 3.03 | 0.51 | 342 |
| RCS-9 | 2.66 | 69 | 67.08 | 68.34 | 68.14 | 3 | 0.51 | 330 |
| RCS-10 | 2.75 | 47.28 | 47.71 | 49.53 | 48.17 | 3.06 | 0.504 | 264 |

## Appendix C: Data, Calculation and Results for Fineness Test

### 1. Fineness of representative cement sample-1:

Specific Gravity = 3

Apparatus constant, K = 21.71

Ss = 3818 (Constant)

V = 1.8525 (Constant)

W = $\rho$V (1 – ϵ)

Where,

W= weight of cement, gm, ρ= density of cement (for Portland cement 3.15 g/cm$^3$ shall be used), V= volume of the cement bed, ϵ= porosity (0.500±0.005)

So, W = 3 x 1.8525 x (1 – 0.50)

= 2.77 gm

Now, 2.77 = 3 x 1.8525 x (1 – ϵ)

Or ϵ = 0.50

Table C1: Permeability test results of representative cement sample-1

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.71 | 43.43 | 43.49 |
| 2 | 2.71 | 43.47 | |
| 3 | 2.71 | 43.58 | |

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.50)\sqrt{(0.50)3}\sqrt{43.49}}{3.00(0.90-0.50)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 2508 cm$^2$/gm

**2. Fineness of representative cement sample-2:**

Specific Gravity = 3.09 gm/cm$^3$

W = $\rho$V (1 – ϵ)

W = 3.09 x 1.8525 x (1 – 0.50)

= 2.86 gm

If W=2.75 gm

2.75= 3.09 x 1.8525 x (1 – ϵ)

Or ϵ = 0.508

Table C2: Permeability test results of representative cement sample-2

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.75 | 77.11 | 78.103 |
| 2 | 2.75 | 78.55 | |
| 3 | 2.75 | 78.65 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.50)\sqrt{(0.508)3}\sqrt{78.103}}{3.09(0.90-0.508)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3642 cm$^2$/gm

**3. Fineness of representative cement sample-3:**

Specific Gravity = 2.91 gm/cm$^3$

W = $\rho$V (1 – ϵ)

W = 2.91 x 1.8525 x (1 – 0.500)

= 2.69 gm

If W=2.63 gm

2.63 = 2.91 x 1.8525 x (1 – ϵ)

Or ϵ = 0.500

If W=2.70 gm

2.70 = 2.91 x 1.8525 x (1 – ϵ)

Or ϵ = 0.487

Table C3: Permeability test results of representative cement sample-3

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.63 | 22.56 | 29.03 |
| 2 | 2.63 | 28.31 | |
| 3 | 2.63 | 36.24 | |
| 4 | 2.70 | 43.10 | 43.503 |
| 5 | 2.70 | 43.53 | |
| 6 | 2.70 | 43.88 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s 3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.500)\sqrt{(0.487)3}\sqrt{43.503}}{2.91(0.90-0.487)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 2408 $cm^2$/gm

**4. Fineness of representative cement sample-4:**

Specific Gravity = 3.15 gm/$cm^3$

W = 3.15 x 1.8525 x (1 – 0.500)

= 2.91 gm

If W=2.75 gm

2.75 = 3.15 x 1.8525 x (1 – ϵ)

Or $\epsilon = 0.52$

Table C4: Permeability test results of representative cement sample-4

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.75 | 55.15 | 56.22 |
| 2 | 2.75 | 56.74 | |
| 3 | 2.75 | 56.79 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.500)\sqrt{(0.52)3}\sqrt{56.22}}{3.15(0.90-0.52)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3028 $cm^2$/gm

**5. Fineness of representative cement sample-5:**

Specific Gravity = 3.00 gm/$cm^3$

W = 3.00 x 1.8525 x (1 – 0.500)

= 2.77 gm

If W=2.66 gm

2.66 = 3.00 x 1.8525 x (1 – $\epsilon$)

Or $\epsilon = 0.51$

Table C5: Permeability test results of representative cement sample-5

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.66 | 70.33 | 71.403 |
| 2 | 2.66 | 72.08 | |
| 3 | 2.66 | 71.80 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.500)\sqrt{(0.51)3}\sqrt{71.403}}{3.00(0.90-0.51)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3394 $cm^2$/gm

**6. Fineness of representative cement sample-6:**

Specific Gravity = 3.09 gm/$cm^3$

W = 3.0 9 x 1.8525 x (1 – 0.500)

= 2.86 gm

If W=2.75 gm

2.75 = 3.09 x 1.8525 x (1 – ϵ)

Or ϵ = 0.51

Table C6: Permeability test results of representative cement sample-6

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.75 | 70.07 | 71.60 |
| 2 | 2.75 | 74.32 | |
| 3 | 2.75 | 70.42 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.500)\sqrt{(0.51)3}\sqrt{71.60}}{3.09(0.90-0.51)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3297 $cm^2$/gm

**7. Fineness of representative cement sample-7:**

Specific Gravity = 3.00 gm/$cm^3$

W = 3.00 x 1.8525 x (1 – 0.500)

= 2.77 gm

If W=2.71 gm

2.71 = 3.00 x 1.8525 x (1 – ϵ)

Or ϵ = 0.50

Table C7: Permeability test results of representative cement sample-7

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.71 | 38.88 | 48.37 |
| 2 | 2.71 | 52.43 | |
| 3 | 2.71 | 53.79 | |

We know,

$$s = \frac{Ss\rho s(bs - \epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b - \epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90 - 0.500)\sqrt{(0.50)3}\sqrt{48.37}}{3.00(0.90 - 0.50)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 2644 $cm^2$/gm

**8. Fineness of representative cement sample-8:**

Specific Gravity = 3.03 gm/$cm^3$

W = 3.03 x 1.8525 x (1 – 0.500)

= 2.80 gm

If W=2.70 gm

2.70 = 3.03 x 1.8525 x (1 – ϵ)

Or ϵ = 0.51

Table C8: Permeability test results of representative cement sample-8

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.70 | 79.12 | 73.85 |
| 2 | 2.70 | 67.42 | |
| 3 | 2.70 | 75.01 | |

We know,

$$s = \frac{Ss\rho s(bs-\epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho(b-\epsilon)\sqrt{\epsilon s3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90-0.50)\sqrt{(0.51)3}\sqrt{73.85}}{3.03(0.90-0.51)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3416 $cm^2$/gm

**9. Fineness of representative cement sample-9:**

Specific Gravity = 3.00 gm/$cm^3$

W = 3.00 x 1.8525 x (1 – 0.500)

= 2.82 gm

If W=2.66 gm

2.66 = 3.00 x 1.8525 x (1 – ϵ)

Or ϵ = 0.51

Table C9: Permeability test results of representative cement sample-9

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.66 | 69.00 | 68.14 |
| 2 | 2.66 | 67.08 | |
| 3 | 2.66 | 68.34 | |

We know,

$$s = \frac{S s \rho s (bs - \epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho (b - \epsilon)\sqrt{\epsilon s 3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90 - 0.500)\sqrt{(0.51)3}\sqrt{68.14}}{3.00(0.90 - 0.51)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 3304 $cm^2$/gm

**10. Fineness of representative cement sample-10:**

Specific Gravity = 3.06 gm/$cm^3$

W = 3.06 x 1.8525 x (1 – 0.500

= 2.82 gm

If W=2.75 gm

2.75 = 3.06 x 1.8525 x (1 – ϵ)

Or ϵ = 0.504

Table C10: Permeability test results of representative cement sample-10

| Sl. No | Weight of Cement (gm) | Time (s) | Average Time (s) |
|---|---|---|---|
| 1 | 2.75 | 47.28 | 48.17 |
| 2 | 2.75 | 47.71 | |
| 3 | 2.75 | 49.53 | |

We know,

$$s = \frac{S s \rho s (bs - \epsilon s)\sqrt{\epsilon 3}\sqrt{T}}{\rho (b - \epsilon)\sqrt{\epsilon s 3}\sqrt{Ts}}$$

$$= \frac{3818 \text{ x } 3.15(0.90 - 0.500)\sqrt{(0.504)3}\sqrt{48.17}}{3.06(0.90 - 0.504)\sqrt{(0.50)3}\sqrt{111.085}}$$

= 2642 $cm^2$/gm

## Appendix D: Data and Results for Normal Consistency Test

Table D1: Normal consistency test result of representative cement sample-1

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31.3% |
| 2 | 650 | 28 | 182 | 4 | 30 | OR |
| 3 | 650 | 30 | 195 | 8 | 30 | 203.45 gm |
| 4 | 650 | 32 | 208 | 11 | 30 | |

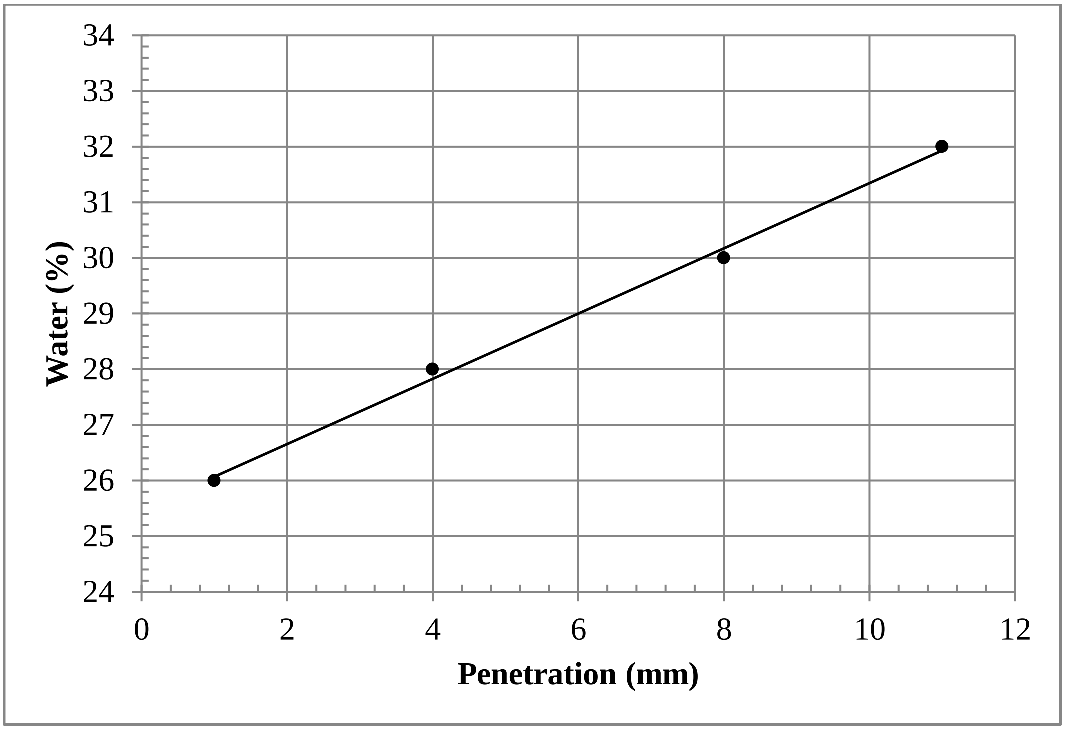


Figure D1: Normal consistency of representative cement sample-1

Table D2: Normal consistency test result of representative cement sample-2

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31.3% OR 203.45 gm |
| 2 | 650 | 28 | 182 | 4 | 30 | |
| 3 | 650 | 30 | 195 | 8 | 30 | |
| 4 | 650 | 32 | 208 | 11 | 30 | |

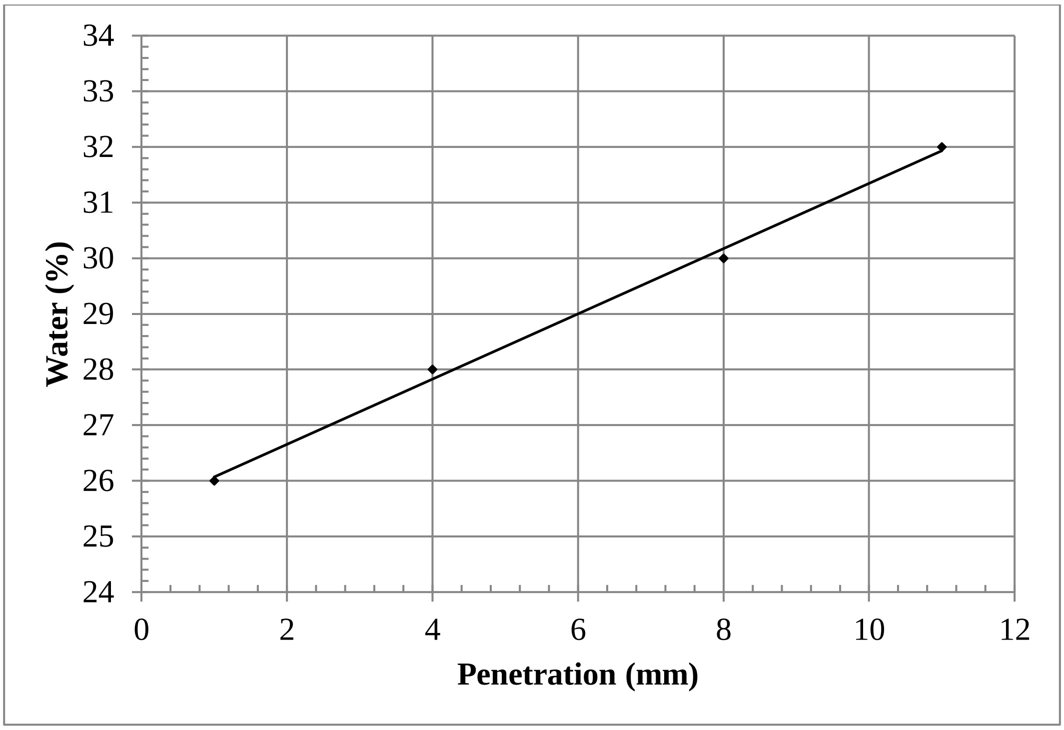


Figure D2: Normal consistency of representative cement sample-2

Table D3: Normal consistency test result of representative cement sample-3

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 25 | 169 | 1 | 30 | 32% OR 208 gm |
| 2 | 650 | 28 | 182 | 4.5 | 30 | |
| 3 | 650 | 30 | 195 | 6.75 | 30 | |
| 4 | 650 | 32 | 208 | 10 | 30 | |

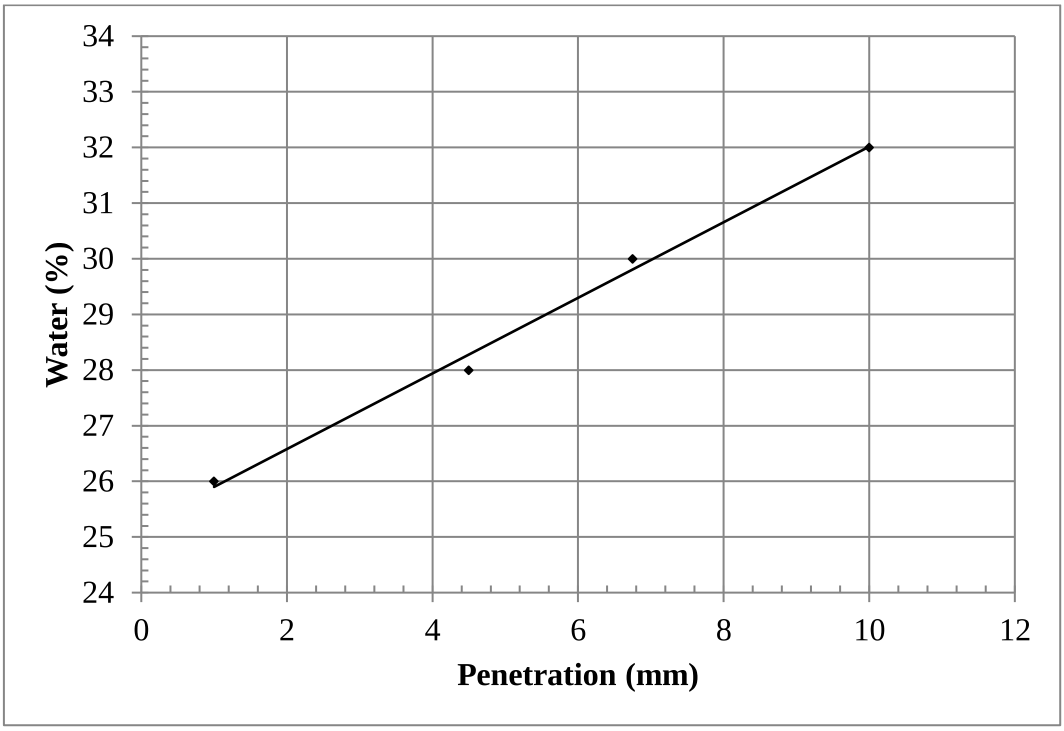


Figure D3: Normal consistency of representative cement sample-3

Table D4: Normal consistency test result of representative cement sample-4

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31.08% OR 202.02 gm |
| 2 | 650 | 28 | 182 | 4 | 30 | |
| 3 | 650 | 30 | 195 | 7 | 30 | |
| 4 | 650 | 32 | 208 | 12.25 | 30 | |

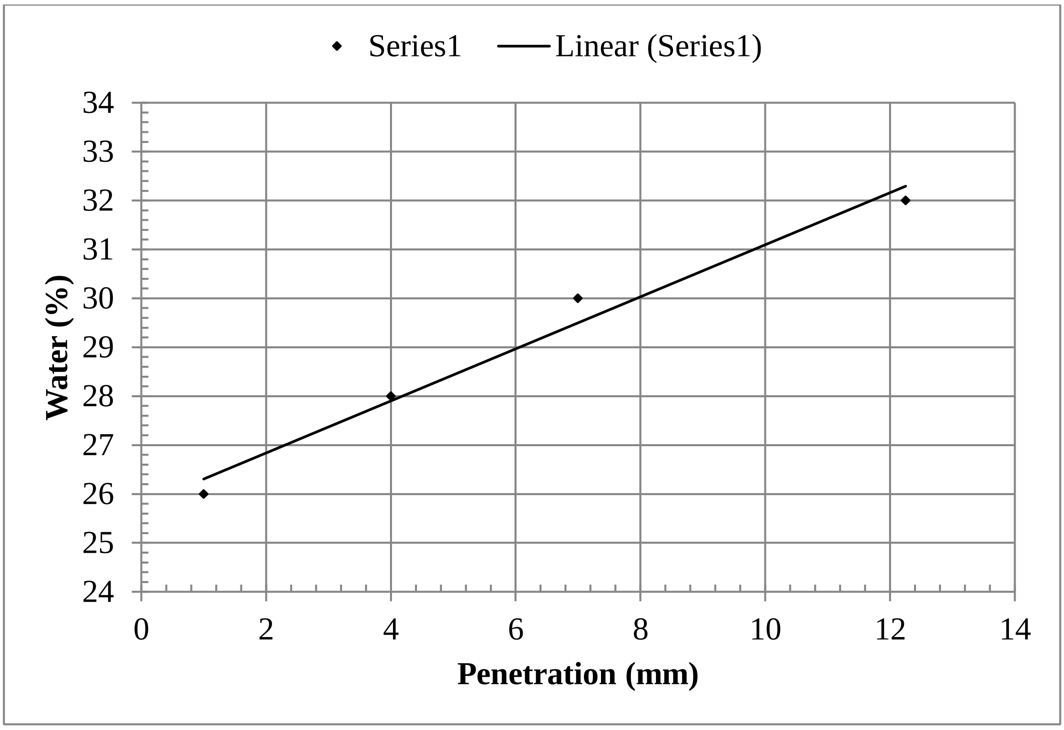


Figure D4: Normal consistency of representative cement sample-4

Table D5: Normal consistency test result of representative cement sample-5

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31.6% OR 205.4 gm |
| 2 | 650 | 28 | 182 | 3 | 30 | |
| 3 | 650 | 30 | 195 | 7 | 30 | |
| 4 | 650 | 32 | 208 | 11 | 30 | |

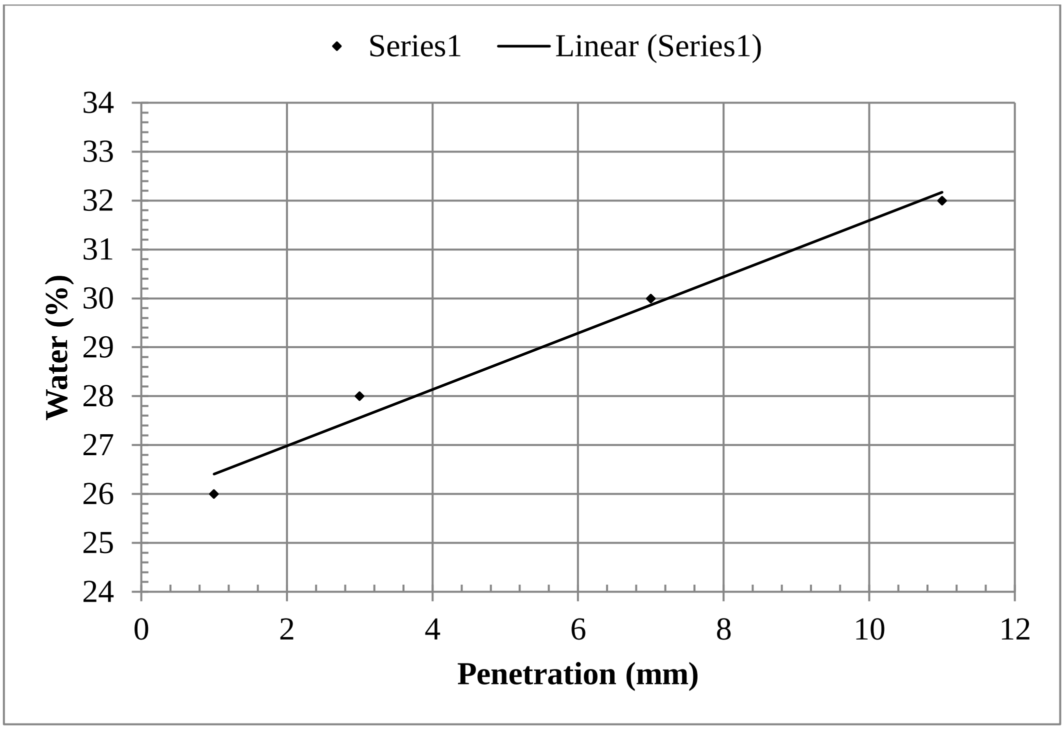


Figure D5: Normal consistency of representative cement sample-5

Table D6: Normal consistency test result of representative cement sample-6

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 2.5 | 30 | 31.45% OR 204.425 gm |
| 2 | 650 | 28 | 182 | 4.5 | 30 | |
| 3 | 650 | 30 | 195 | 7.5 | 30 | |
| 4 | 650 | 32 | 208 | 11 | 30 | |

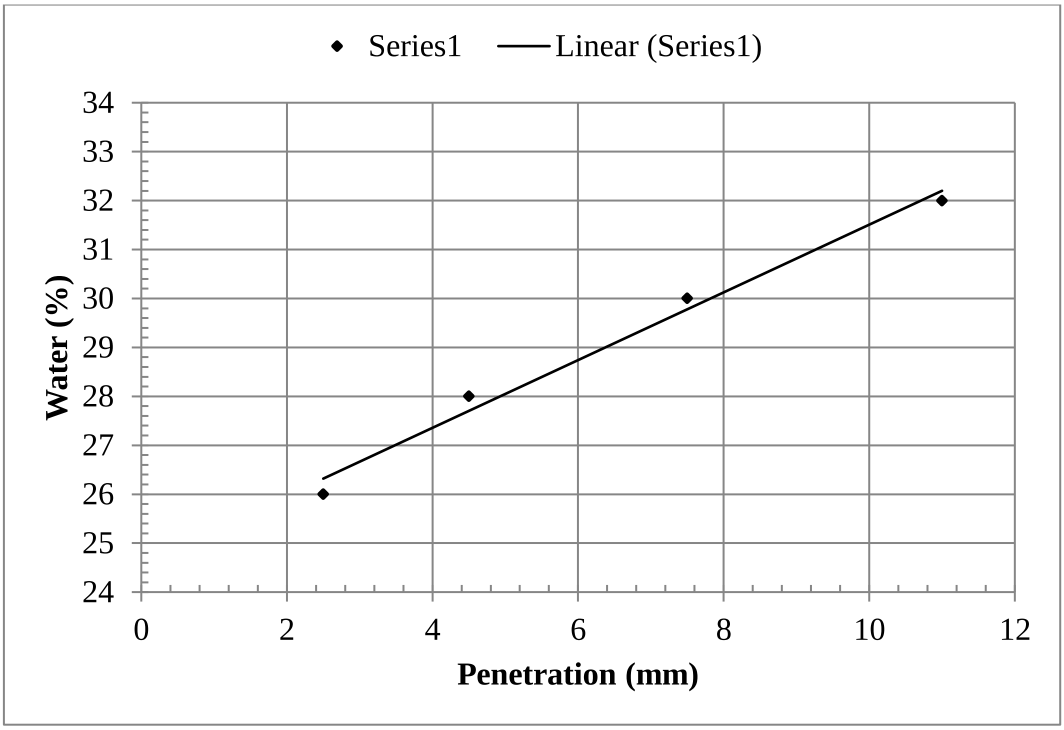


Figure D6: Normal consistency of representative cement sample-6

Table D7: Normal consistency test result of representative cement sample-7

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 0 | 30 | 28.45% OR 184.925 gm |
| 2 | 650 | 28 | 182 | 7 | 30 | |
| 3 | 650 | 30 | 195 | 16 | 30 | |
| 4 | 650 | 32 | 208 | 27 | 30 | |

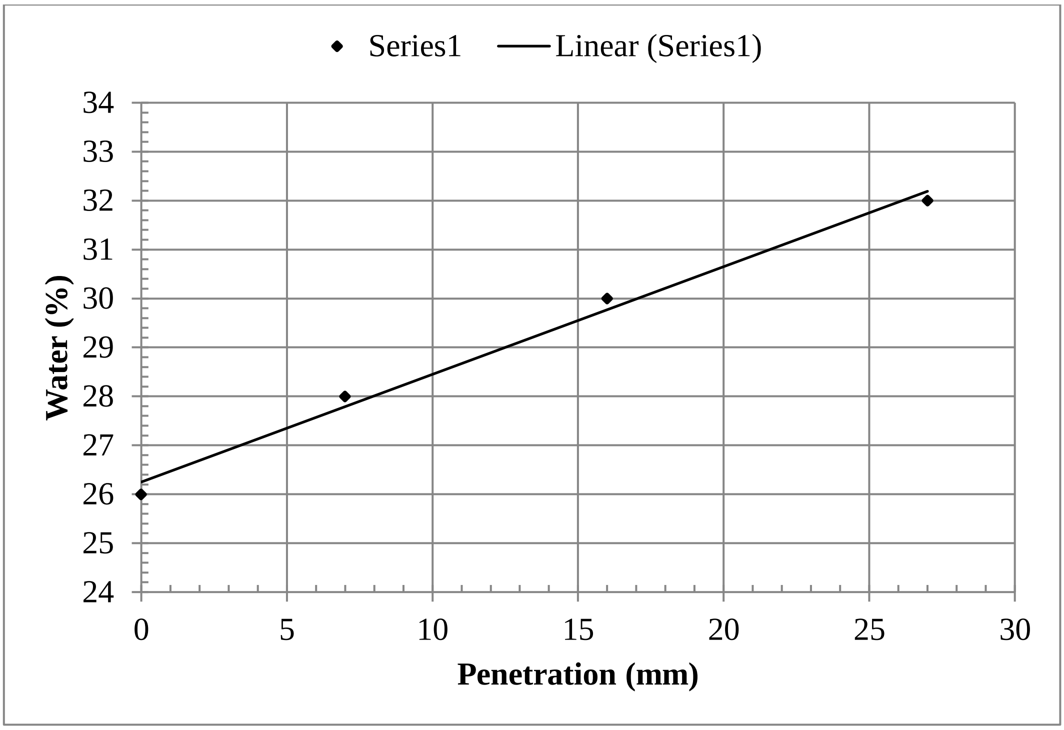


Figure D7: Normal consistency of representative cement sample-7

Table D8: Normal consistency test result of representative cement sample-8

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31% OR 201.5gm |
| 2 | 650 | 28 | 182 | 4 | 30 | |
| 3 | 650 | 30 | 195 | 8 | 30 | |
| 4 | 650 | 32 | 208 | 12 | 30 | |

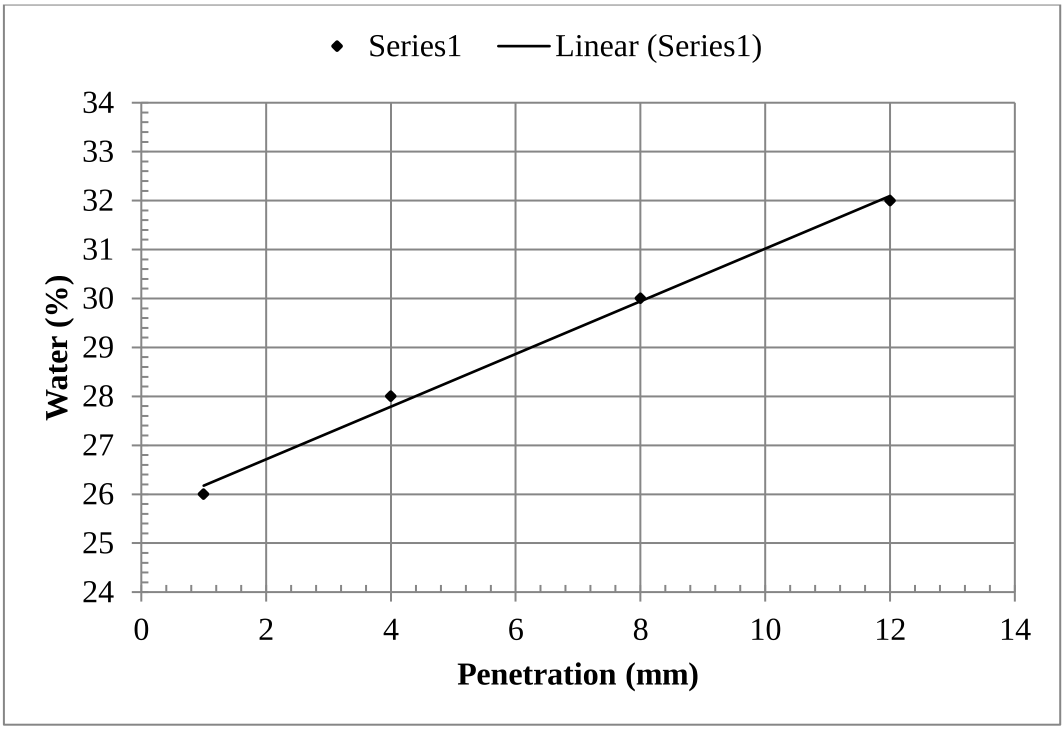


Figure D8: Normal consistency of representative cement sample-8

Table D9: Normal consistency test result of representative cement sample-9

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 31.2% OR 202.80 gm |
| 2 | 650 | 28 | 182 | 4 | 30 | |
| 3 | 650 | 30 | 195 | 8 | 30 | |
| 4 | 650 | 32 | 208 | 11.50 | 30 | |

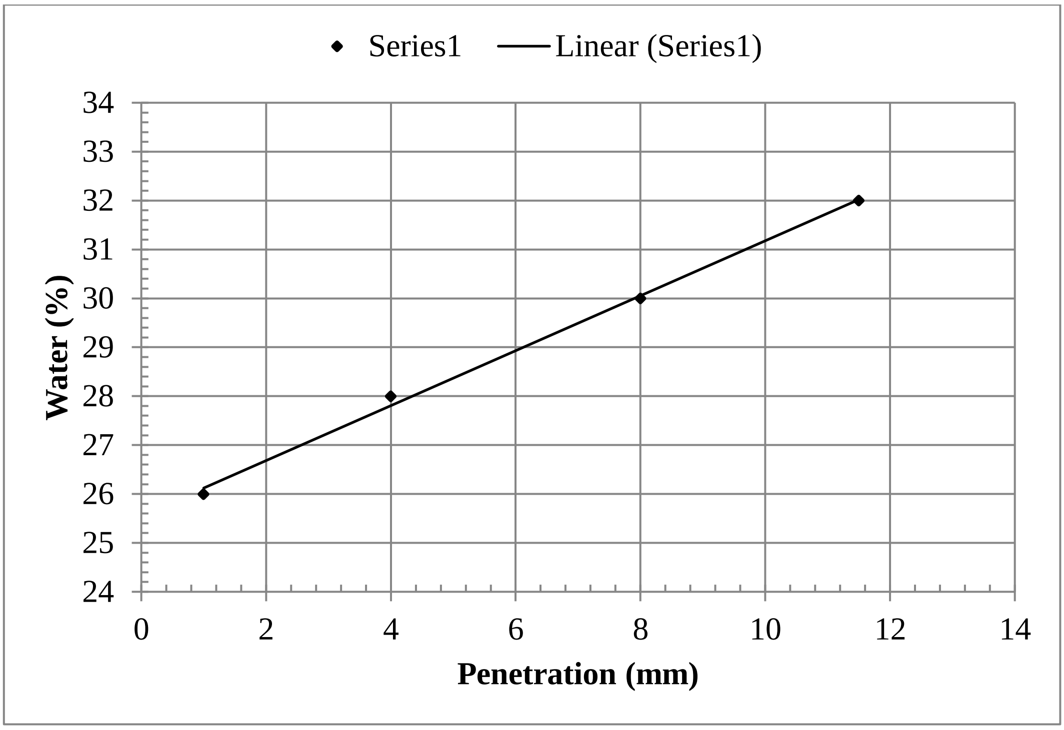


Figure D9: Normal consistency of representative cement sample-9

Table D10: Normal consistency test result of representative cement sample-10

| Sl. No | Cement (gm) | Water (%) | Water (gm) | Penetration (mm) | Time (s) | Required Water for 10mm Penetration |
|---|---|---|---|---|---|---|
| 1 | 650 | 26 | 169 | 1 | 30 | 30.85% OR 200.52 gm |
| 2 | 650 | 28 | 182 | 4 | 30 | |
| 3 | 650 | 30 | 195 | 8 | 30 | |
| 4 | 650 | 32 | 208 | 12.50 | 30 | |

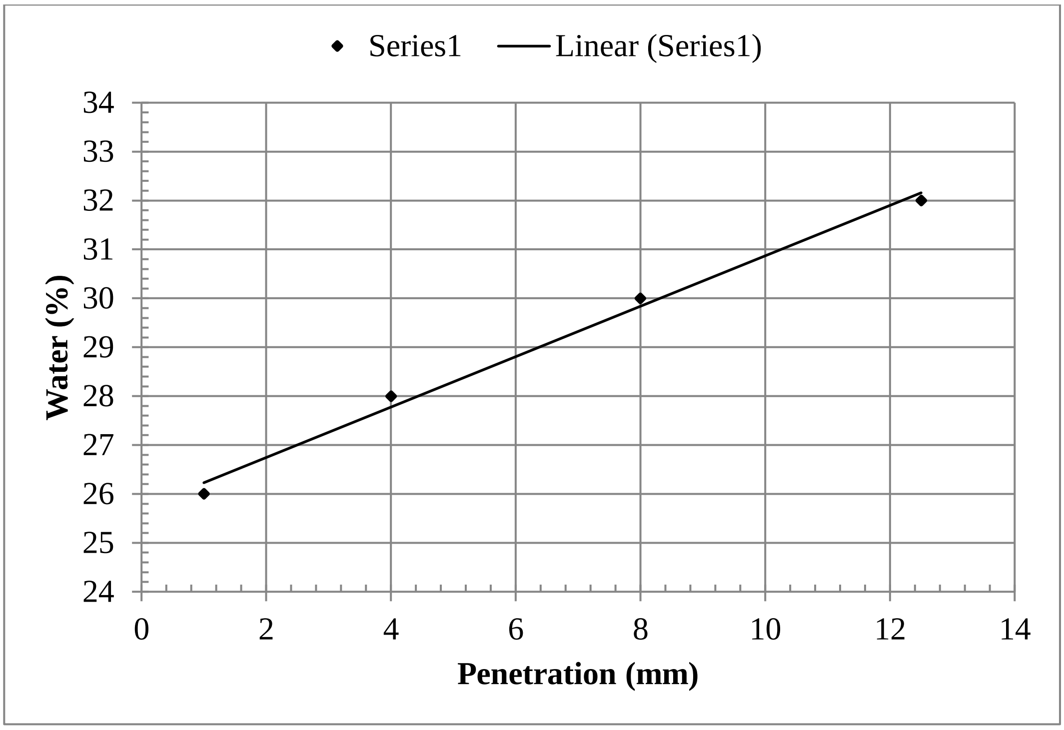


Figure D10: Normal consistency of representative cement sample-10

**Appendix E: Data and Results for Setting Time Test**

Table E1: Setting time test result of representative cement sample-1

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 38 | 36 | 34 | 23 | 3 | 0.5 | | |
| Initial setting time (25 mm) | 177 min | | | | | | | | | | | | | |
| Final setting time (0.5mm) | 210 min | | | | | | | | | | | | | |

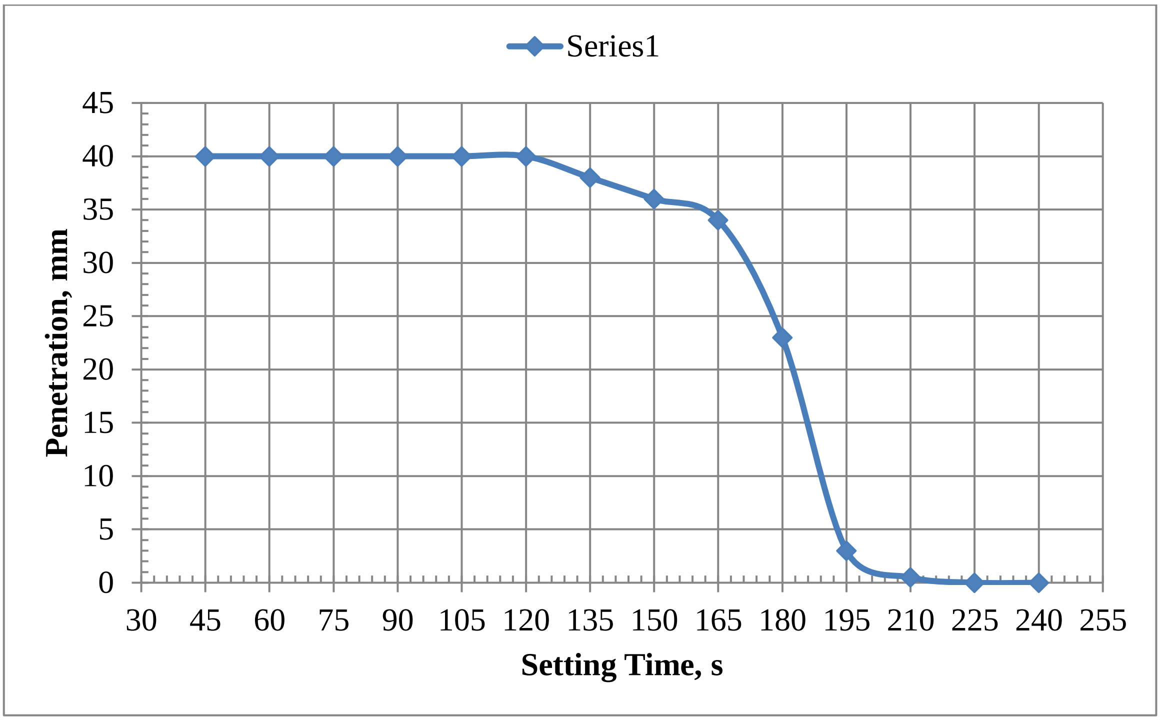


Figure E1: Setting time of representative cement sample-1

Table E2: Setting time test result of representative cement sample-2

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 38 | 26 | 20 | 15 | 3 | 0.5 | | |
| Initial setting time (25 mm) | | 153 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 210 | min | | | | | | | | | | | |

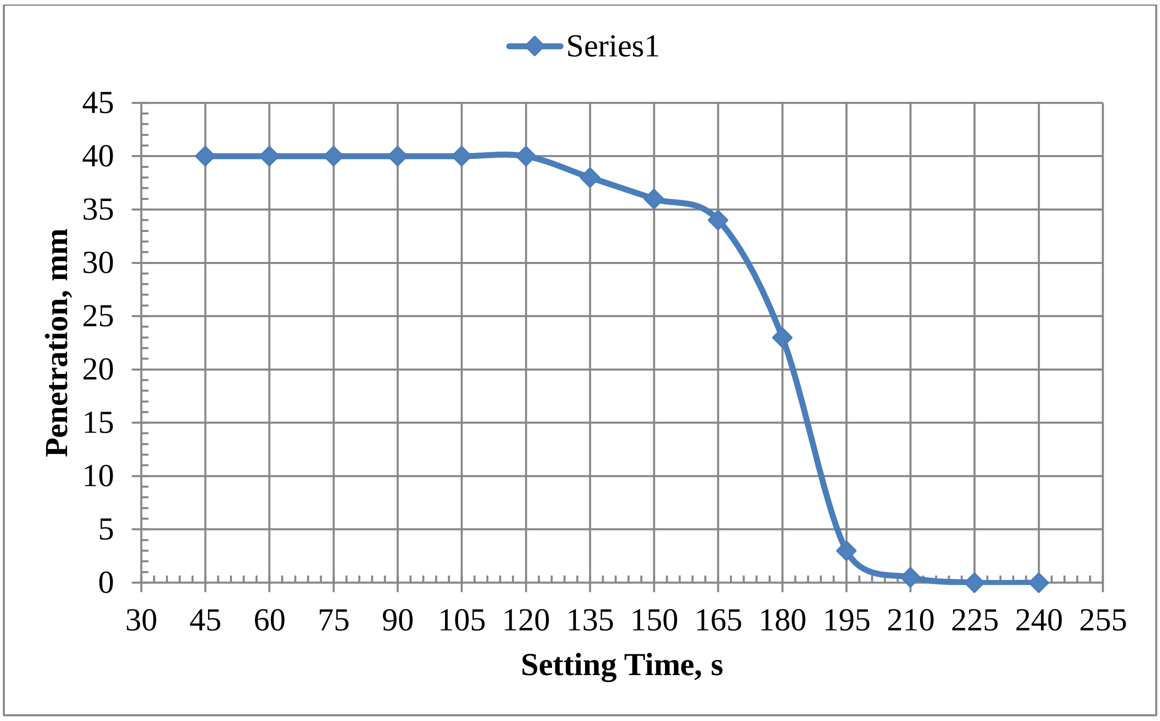


Figure E2: Setting time of representative cement sample-2

Table E3: Setting time test result of representative cement sample-3

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 38 | 35 | 32 | 5 | 3 | 1.5 | 0.5 | | | |
| Initial setting time (25 mm) | | 139 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 195 | min | | | | | | | | | | | |

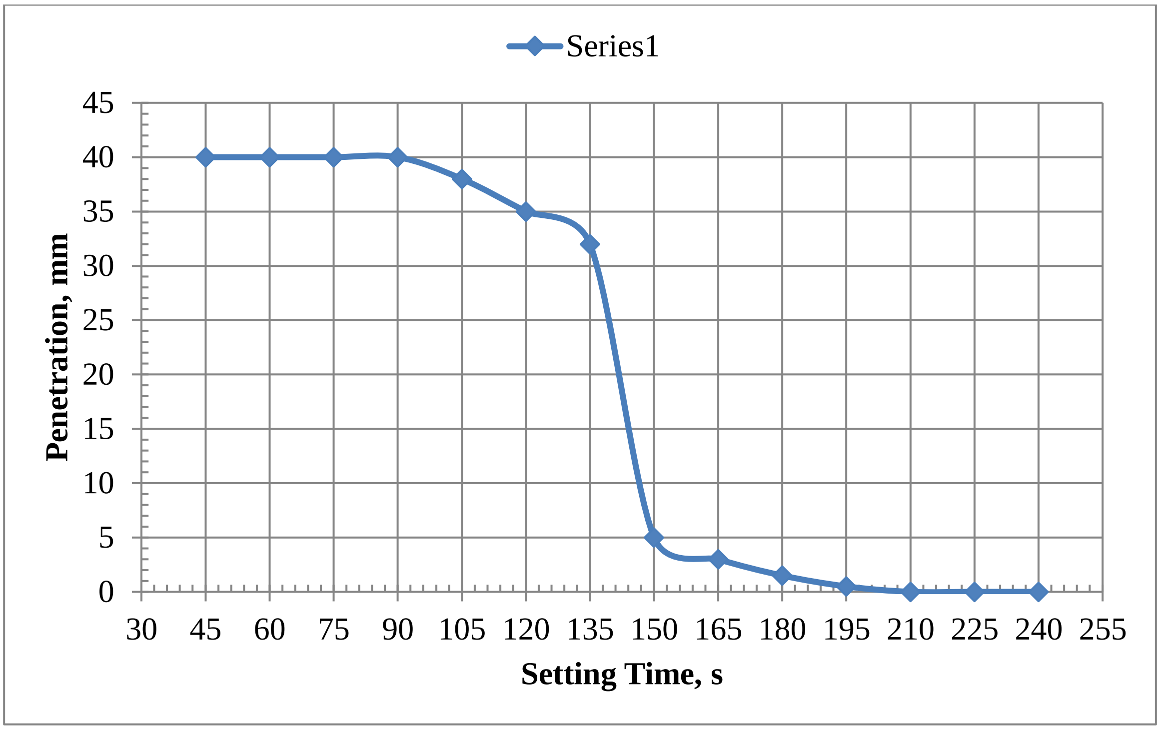


Figure E3: Setting time of representative cement sample-3

Table E4: Setting time test result of representative cement sample-4

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 38 | 24 | 19 | 14 | 9 | 2 | 0.5 | | | |
| Initial setting time (25 mm) | | 119 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 195 | min | | | | | | | | | | | |

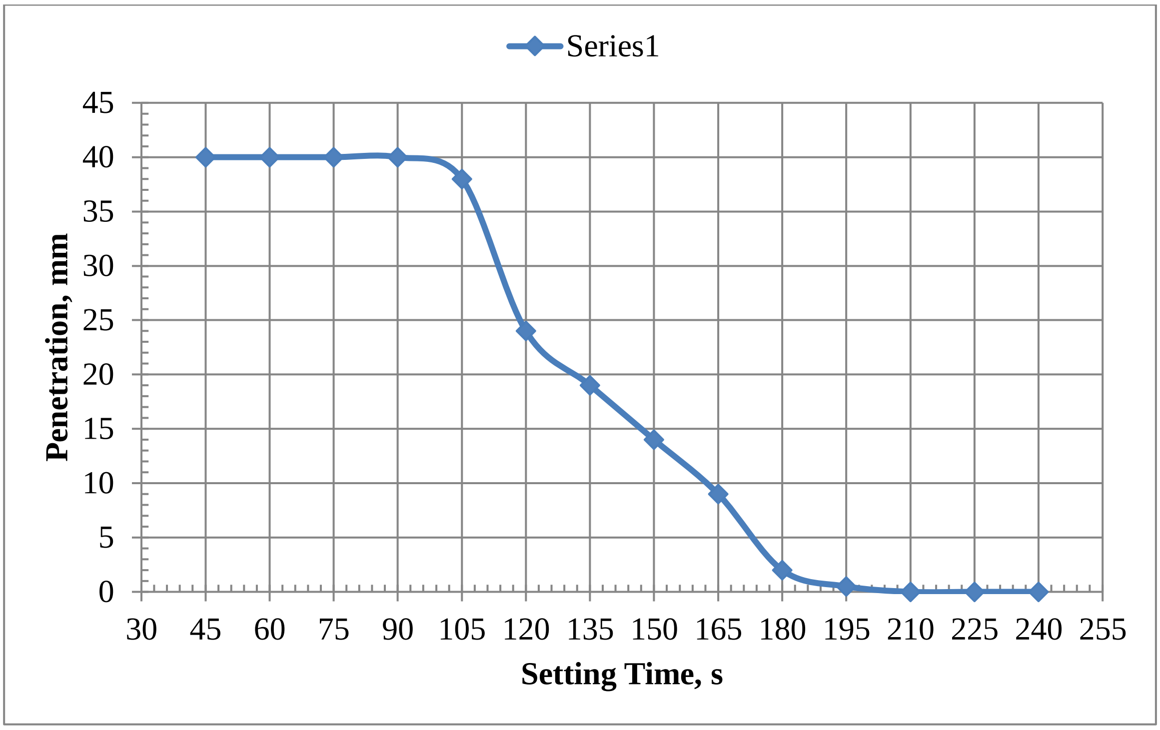


Figure E4: Setting time of representative cement sample-4

Table E5: Setting time test result of representative cement sample-5

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 38 | 32 | 4 | 2.5 | 0.5 | | |
| Initial setting time (25 mm) | | 169 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 210 | min | | | | | | | | | | | |

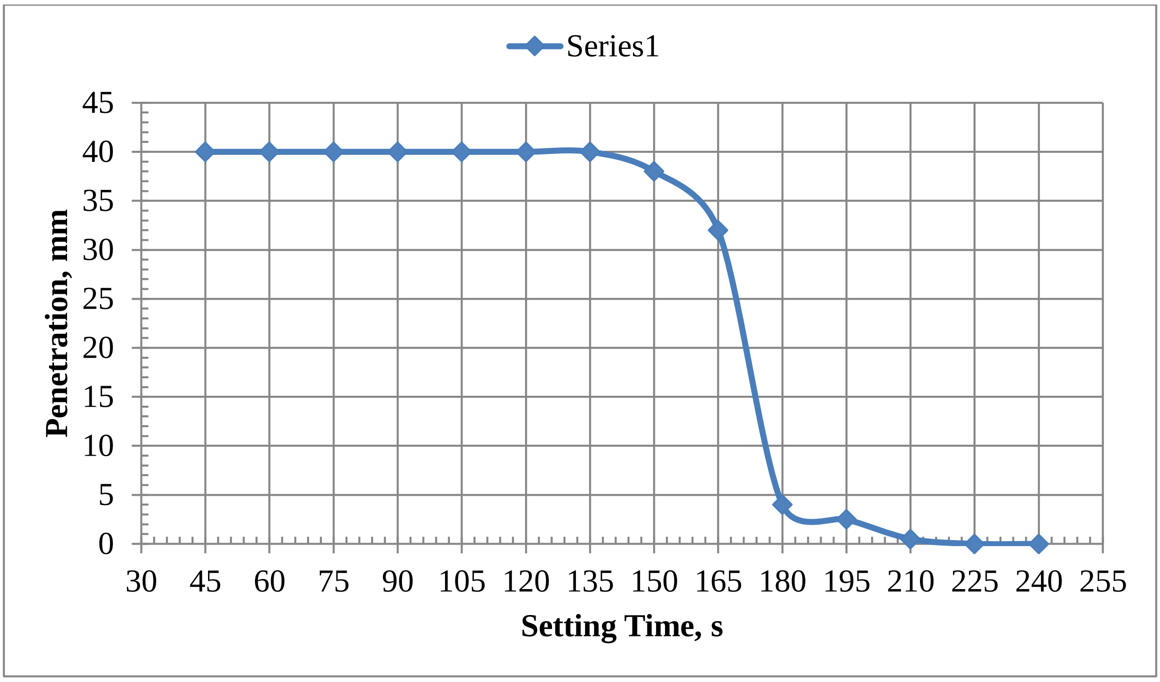


Figure E5: Setting time of representative cement sample-5

Table E6: Setting time test result of representative cement sample-6

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 35 | 22 | 10 | 3 | 0.5 | | | |
| Initial setting time (25 mm) | | 147 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 195 | min | | | | | | | | | | | |

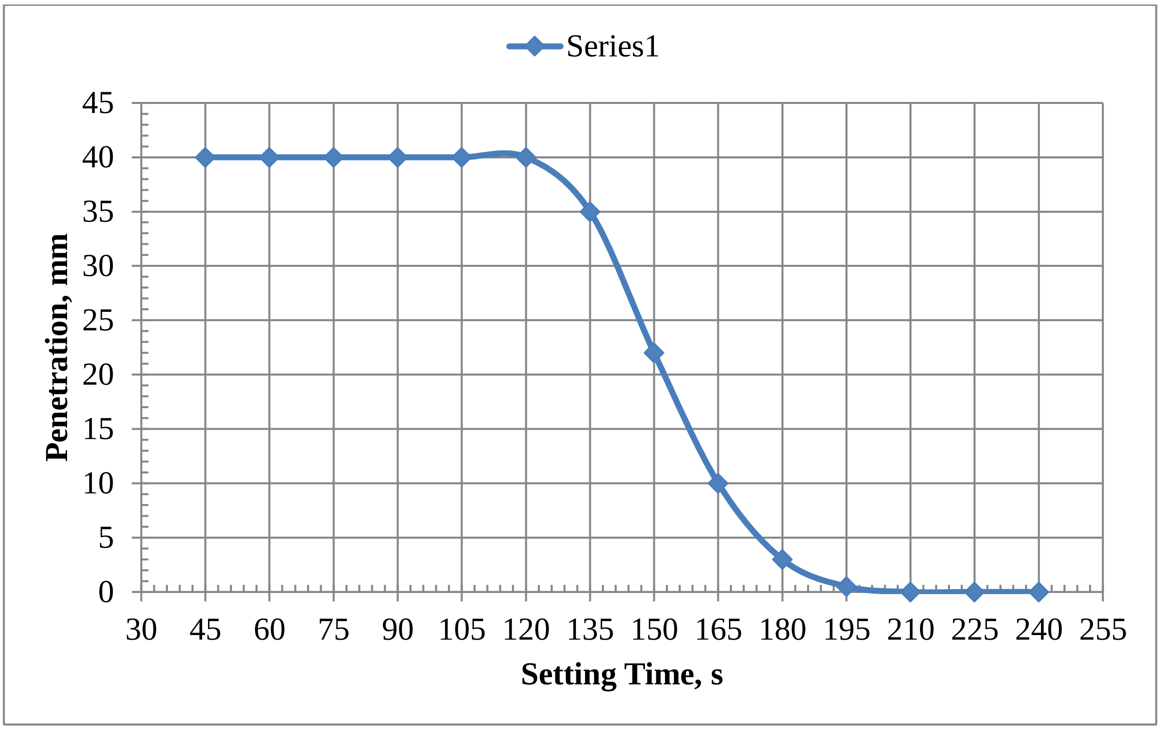


Figure E6: Setting time of representative cement sample-6

Table E7: Setting time test result of representative cement sample-7

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 38 | 35 | 29 | 15 | 4 | 1.5 | 0.5 | | | |
| Initial setting time (25 mm) | | 139 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 195 | min | | | | | | | | | | | |

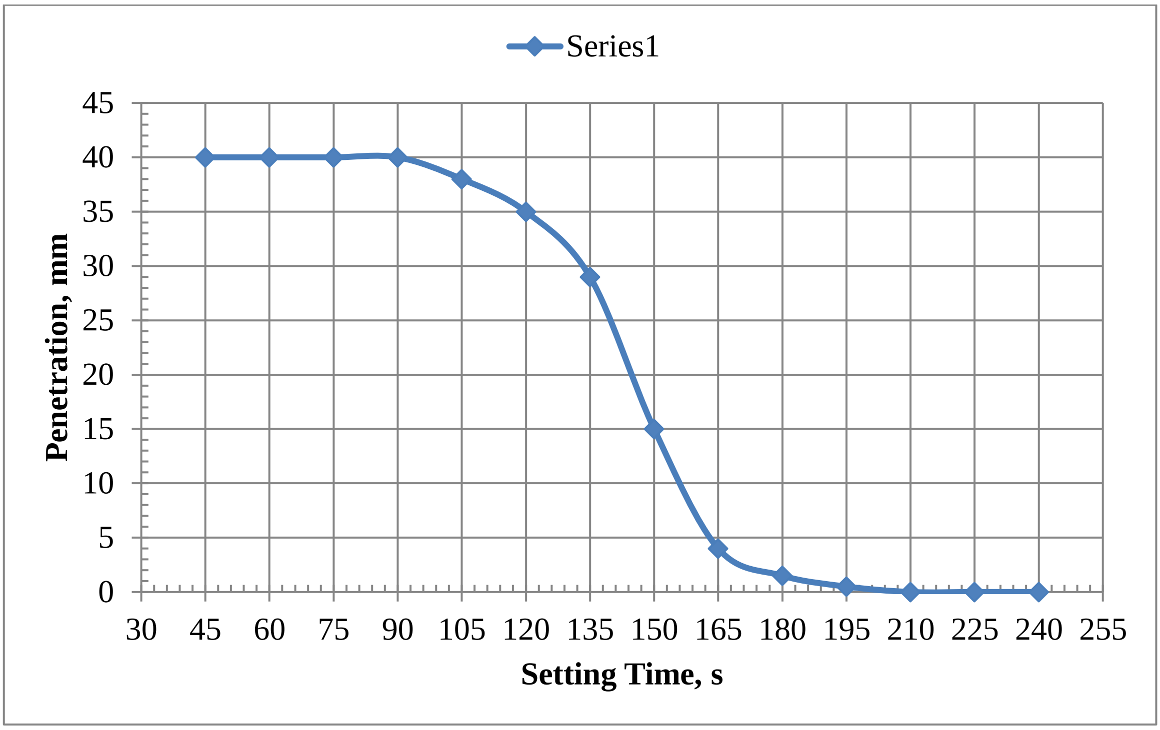


Figure E7: Setting time of representative cement sample-7

Table E8: Setting time test result of representative cement sample-8

| Time (min) | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 35 | 31 | 29 | 26 | 23 | 15 | 8 | 2 | 0.5 |
| Initial setting time (25 mm) | | 170 | min | | | | | | | | | |
| Final setting time (0.5mm) | | 240 | min | | | | | | | | | |

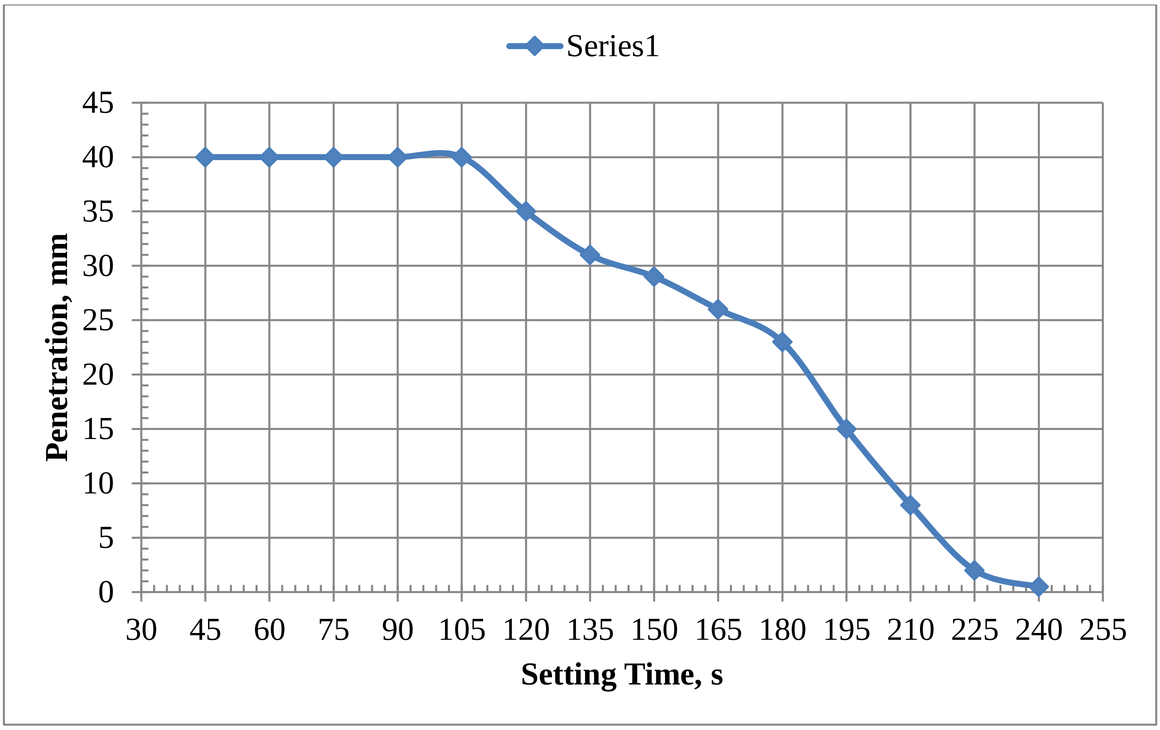


Figure E8: Setting time of representative cement sample-8

Table E9: Setting time test result of representative cement sample-9

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 34 | 24 | 20 | 5 | 1.5 | 0.5 |
| Initial setting time (25 mm) | | 179 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 240 | min | | | | | | | | | | | |

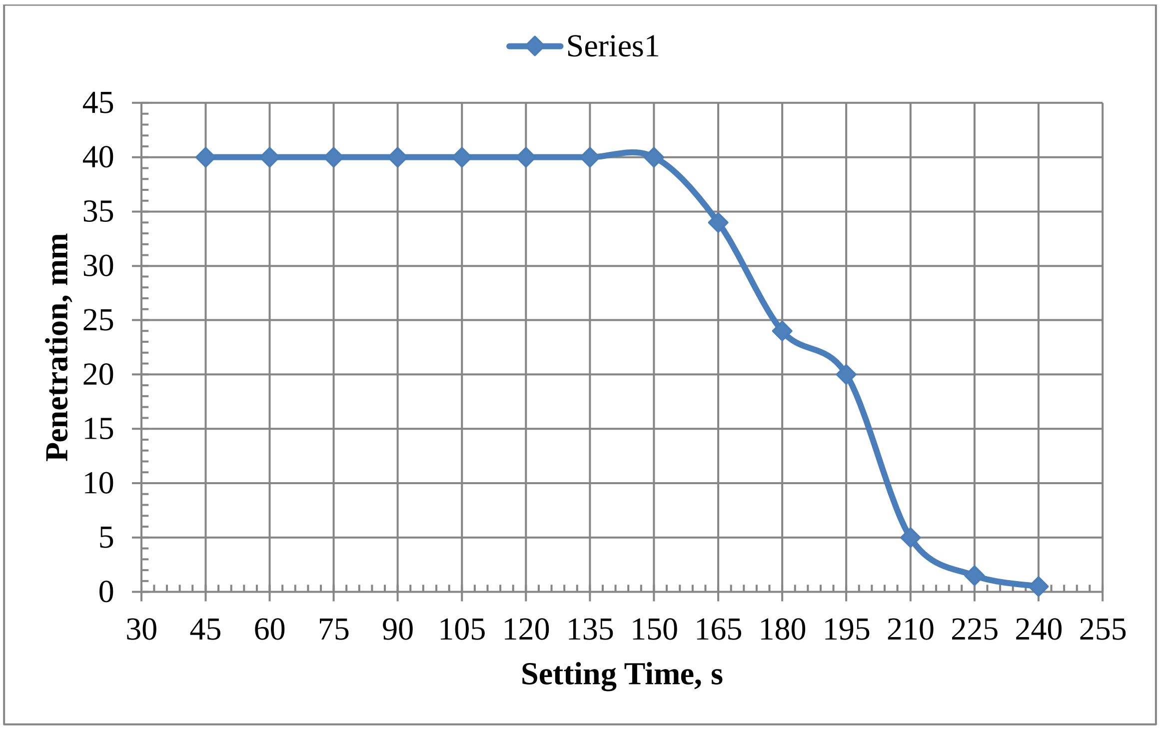


Figure E9: Setting time of representative cement sample-9

Table E10: Setting time test result of representative cement sample-10

| Time (min) | 45 | 60 | 75 | 90 | 105 | 120 | 135 | 150 | 165 | 180 | 195 | 210 | 225 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Penetration (mm) | 40 | 40 | 40 | 40 | 40 | 40 | 34 | 29 | 24 | 18 | 10 | 2 | 0.5 | |
| Initial setting time (25 mm) | | 162 | min | | | | | | | | | | | |
| Final setting time (0.5mm) | | 225 | min | | | | | | | | | | | |

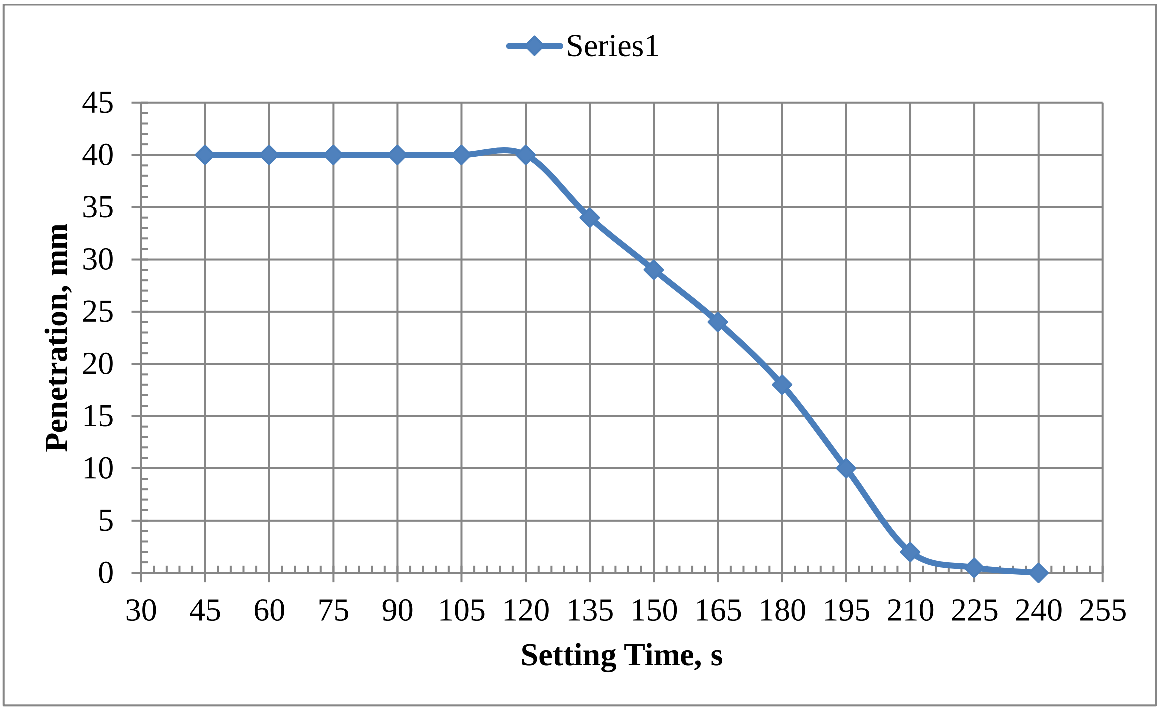


Figure E10: Setting time of representative cement sample-10

**Appendix F: Data and Results for Compressive Strength Test of Cement Mortars**

Table F1: Compressive strength test (mortar) result of representative cement sample-1

| Age (days) | Date of Testing | Specimen No. | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 15.06 | 14.03 | 2034.35 |
| | | 2 | 13.63 | | |
| | | 3 | 13.39 | | |
| 7 | 04.01.18 | 1 | 15.06 | 20.22 | 2931.90 |
| | | 2 | 23.66 | | |
| | | 3 | 21.94 | | |
| 28 | 25.01.18 | 1 | 26.11 | 27.25 | 3951.25 |
| | | 2 | 27.72 | | |
| | | 3 | 27.91 | | |

Table F2: Compressive strength test (mortar) result of representative cement sample-2

| Age (days) | Date of Testing | Specimen No. | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 15.39 | 15.08 | 2187 |
| | | 2 | 16.51 | | |
| | | 3 | 13.35 | | |
| 7 | 04.01.18 | 1 | 24.29 | 20.97 | 3041 |
| | | 2 | 19.45 | | |
| | | 3 | 19.17 | | |
| 28 | 25.01.18 | 1 | 26.85 | 24.47 | 3548.15 |
| | | 2 | 20.63 | | |
| | | 3 | 25.93 | | |

Table F3: Compressive strength test (mortar) result of representative cement sample-3

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 15.61 | 16.473 | 2388.63 |
| | | 2 | 16.64 | | |
| | | 3 | 17.17 | | |
| 7 | 04.01.18 | 1 | 23.06 | 22.943 | 3326.78 |
| | | 2 | 20.86 | | |
| | | 3 | 24.91 | | |
| 28 | 25.01.18 | 1 | 34.92 | 34.586 | 5015.07 |
| | | 2 | 32.43 | | |
| | | 3 | 36.41 | | |

Table F4: Compressive strength test (mortar) result of representative cement sample-4

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 14.46 | 14.843 | 2152.28 |
| | | 2 | 14.84 | | |
| | | 3 | 15.23 | | |
| 7 | 04.01.18 | 1 | 19.29 | 17.81 | 2582.45 |
| | | 2 | 19.03 | | |
| | | 3 | 15.11 | | |
| 28 | 25.01.18 | 1 | 39.96 | 38.38 | 5565.10 |
| | | 2 | 37.58 | | |
| | | 3 | 37.60 | | |

Table F5: Compressive strength test (mortar) result of representative cement sample-5

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 15.63 | 13.527 | 1961.37 |
| | | 2 | 12.18 | | |
| | | 3 | 12.77 | | |
| 7 | 04.01.18 | 1 | 15.62 | 15.033 | 2179.83 |
| | | 2 | 20.82 | | |
| | | 3 | 8.66 | | |
| 28 | 25.01.18 | 1 | 22.56 | 24.743 | 3587.78 |
| | | 2 | 27.37 | | |
| | | 3 | 24.30 | | |

Table F6: Compressive strength test (mortar) result of representative cement sample-6

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 16.29 | 15.27 | 2214 |
| | | 2 | 15.34 | | |
| | | 3 | 14.18 | | |
| 7 | 04.01.18 | 1 | 25.24 | 22.44 | 3254 |
| | | 2 | 22.45 | | |
| | | 3 | 19.63 | | |
| 28 | 25.01.18 | 1 | 25.40 | 25.05 | 3633 |
| | | 2 | 23.38 | | |
| | | 3 | 26.39 | | |

Table F7: Compressive strength test (mortar) result of representative cement sample-7

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 16.15 | 15.71 | 2278 |
| | | 2 | 15.21 | | |
| | | 3 | 15.78 | | |
| 7 | 04.01.18 | 1 | 24.82 | 23.43 | 3397 |
| | | 2 | 22.20 | | |
| | | 3 | 23.26 | | |
| 28 | 25.01.18 | 1 | 26.61 | 25.71 | 3728 |
| | | 2 | 27.04 | | |
| | | 3 | 23.48 | | |

Table F8: Compressive strength test (mortar) result of representative cement sample-8

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 12.19 | 12.197 | 1768.52 |
| | | 2 | 13.53 | | |
| | | 3 | 10.87 | | |
| 7 | 04.01.18 | 1 | 17.84 | 19.363 | 2807.68 |
| | | 2 | 20.73 | | |
| | | 3 | 19.52 | | |
| 28 | 25.01.18 | 1 | 39.18 | 34.283 | 4971.08 |
| | | 2 | 37.81 | | |
| | | 3 | 25.86 | | |

Table F9: Compressive strength test (mortar) result of representative cement sample-9

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 13.91 | 13.39 | 1941.55 |
| | | 2 | 14.59 | | |
| | | 3 | 11.67 | | |
| 7 | 04.01.18 | 1 | 19.63 | 18.313 | 2655.43 |
| | | 2 | 17.94 | | |
| | | 3 | 17.37 | | |
| 28 | 25.01.18 | 1 | 39.99 | 33.966 | 4925.17 |
| | | 2 | 20.81 | | |
| | | 3 | 41.10 | | |

Table F10: Compressive strength test (mortar) result of representative cement sample-10

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 3 | 31.12.17 | 1 | 15.11 | 13.133 | 1904.33 |
| | | 2 | 11.55 | | |
| | | 3 | 12.74 | | |
| 7 | 04.01.18 | 1 | 20.55 | 21.113 | 3061.43 |
| | | 2 | 20.36 | | |
| | | 3 | 22.43 | | |
| 28 | 25.01.18 | 1 | 38.19 | 36.983 | 5362.58 |
| | | 2 | 36.52 | | |
| | | 3 | 36.24 | | |

## Appendix G: Data and Results for Compressive Strength Test of Cylindrical Concrete Specimens

Table G1: Comp. strength test (cylindrical) result of representative cement sample-1

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 12.88 | 13.716 | 1988.92 |
| | | 2 | 11.48 | | |
| | | 3 | 16.79 | | |
| 14 | 11.01.18 | 1 | 19.49 | 21.106 | 3060.47 |
| | | 2 | 19.83 | | |
| | | 3 | 24.00 | | |
| 28 | 25.01.18 | 1 | 34.55 | 33.53 | 4861 |
| | | 2 | 34.50 | | |
| | | 3 | 31.54 | | |

Table G2: Comp. strength test (cylindrical) result of representative cement sample-2

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 16.50 | 16.726 | 2425.37 |
| | | 2 | 19.03 | | |
| | | 3 | 14.65 | | |
| 14 | 11.01.18 | 1 | 18.94 | 18.806 | 2726.97 |
| | | 2 | 21.12 | | |
| | | 3 | 16.36 | | |
| 28 | 25.01.18 | 1 | 44.25 | 41.773 | 6057.13 |
| | | 2 | 37.61 | | |
| | | 3 | 43.46 | | |

Table G3: Comp. strength test (cylindrical) result of representative cement sample-3

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 13.08 | 18.946 | 2747.27 |
| | | 2 | 25.76 | | |
| | | 3 | 18.00 | | |
| 14 | 11.01.18 | 1 | 17.51 | 21.303 | 3088.98 |
| | | 2 | 23.13 | | |
| | | 3 | 23.27 | | |
| 28 | 25.01.18 | 1 | 39.31 | 39.426 | 5716.87 |
| | | 2 | 43.58 | | |
| | | 3 | 35.39 | | |

Table G4: Comp. strength test (cylindrical) result of representative cement sample-4

| Age (days) | Date of Testing | Specime n No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 16.99 | 16.20 | 2349.00 |
| | | 2 | 16.04 | | |
| | | 3 | 15.57 | | |
| 14 | 11.01.18 | 1 | 20.17 | 20.73 | 3005.85 |
| | | 2 | 22.27 | | |
| | | 3 | 19.75 | | |
| 28 | 25.01.18 | 1 | 24.99 | 33.806 | 4901.97 |
| | | 2 | 38.02 | | |
| | | 3 | 38.41 | | |

Table G5: Comp. strength test (cylindrical) result of representative cement sample-5

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 17.65 | 17.73 | 2860.85 |
| | | 2 | 26.38 | | |
| | | 3 | 15.16 | | |
| 14 | 11.01.18 | 1 | 27.17 | 23.516 | 3409.92 |
| | | 2 | 22.44 | | |
| | | 3 | 20.94 | | |
| 28 | 25.01.18 | 1 | 42.55 | 37.216 | 5396.42 |
| | | 2 | 38.50 | | |
| | | 3 | 30.60 | | |

Table G6: Comp. strength test (cylindrical) result of representative cement sample-6

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 21.81 | 20.79 | 3014.55 |
| | | 2 | 20.49 | | |
| | | 3 | 20.07 | | |
| 14 | 11.01.18 | 1 | 28.50 | 28.533 | 4137.33 |
| | | 2 | 26.94 | | |
| | | 3 | 30.16 | | |
| 28 | 25.01.18 | 1 | 38.54 | 39.68 | 5753.60 |
| | | 2 | 40.82 | | |
| | | 3 | - | | |

Table G7: Comp. strength test (cylindrical) result of representative cement sample-7

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 18.51 | 19.44 | 2818.80 |
| | | 2 | 19.89 | | |
| | | 3 | 19.92 | | |
| 14 | 11.01.18 | 1 | 25.14 | 24.156 | 3502.72 |
| | | 2 | 23.37 | | |
| | | 3 | 23.96 | | |
| 28 | 25.01.18 | 1 | 39.22 | 37.08 | 5376.60 |
| | | 2 | 34.94 | | |
| | | 3 | - | | |

Table G8: Comp. strength test (cylindrical) result of representative cement sample-8

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 8.73 | 11.85 | 1718.25 |
| | | 2 | 15.56 | | |
| | | 3 | 11.26 | | |
| 14 | 11.01.18 | 1 | 11.72 | 13.465 | 1952.52 |
| | | 2 | 15.62 | | |
| | | 3 | 13.05 | | |
| 28 | 25.01.18 | 1 | 22.53 | 26.483 | 3840.08 |
| | | 2 | 34.78 | | |
| | | 3 | 22.14 | | |

Table G9: Comp. strength test (cylindrical) result of representative cement sample-9

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 19.59 | 15.70 | 2276.50 |
| | | 2 | 11.71 | | |
| | | 3 | 15.80 | | |
| 14 | 11.01.18 | 1 | 17.81 | 18.736 | 2716.82 |
| | | 2 | 16.16 | | |
| | | 3 | 22.24 | | |
| 28 | 25.01.18 | 1 | 43.56 | 37.266 | 5403.67 |
| | | 2 | 31.19 | | |
| | | 3 | 37.05 | | |

Table G10: Comp. strength test (cylindrical) result of representative cement sample-10

| Age (days) | Date of Testing | Specimen No | Compressive Strength (MPa) | Average Compressive Strength (MPa) | Average Compressive Strength (psi) |
|---|---|---|---|---|---|
| 7 | 04.01.18 | 1 | 17.09 | 17.63 | 2556.35 |
| | | 2 | 17.08 | | |
| | | 3 | 18.72 | | |
| 14 | 11.01.18 | 1 | 14.79 | 17.873 | 2591.63 |
| | | 2 | 14.78 | | |
| | | 3 | 24.05 | | |
| 28 | 25.01.18 | 1 | 34.09 | 38.883 | 5638.08 |
| | | 2 | 41.60 | | |
| | | 3 | 40.96 | | |