EFFECT OF SILICA FUME INCLUSION ON PROPERTIES OF HIGH STRENGTH CONCRETE CONTAINING HIGH VOLUME OF STEEL SLAG

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By

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ABSTRAK

Pengunnan tanah granulated relast slag konkrit adalah berfaedah dari pandangan ekonomi, alam sekitar dan teknikal. untuk menghancurkan gerek letupan konkrit dalam konkrit adalah berfaedah dari pandangan ekonomi, alam sekitar dan teknikal. Walau bagaimanapun, penggunaan sanga terutamanya dalam jumlah tinggi boleh menjejaskan kekuatan dan sifat konkrit lain. Oleh itu, kajian ini meneroka kemungkinan menggunakan wasap silika sebagai penggantian sebahagian daripada sanga dalam konkrit kekuatan tinggi yang mengandungi jumlah isipadu yang tinggi. Campuran konkrit berkekuatan tinggi dengan kekuatan 28 hari sebanyak 70 MPa. Campuran yang serupa adalah sebanding tetapi 60% daripada simen Portland biasa diganti dengan sanga secara massal untuk massa. Tambahan pula, empat campuran konkrit lain pula dipengaruhi oleh sebahagiannya menggantikan kandungan sanga dengan wasap silika pada 5, 10, 15 dan 20%. Kesan penggabungan sanga pada kebolehkerjaan, ketumpatan, kekuatan mampatan, keliangan dan penyerapan air konkrit telah diselidiki. Keputusan menunjukkan bahawa penggunaan sanga dalam kombinasi dengan wasap silika cenderung untuk mengurangkan kebolehkerjaan konkrit kekuatan tinggi. Campuran konkrit yang mengandungi sanga serta kombinasi sanga dan silika mempamerkan kepadatan yang lebih tinggi daripada konkrit kawalan. Kemasukan wasap silika meningkatkan kekuatan konkrit berkekuatan tinggi yang mengandungi isipadu tinggi sanga, khususnya kandungan wasap silika yang lebih tinggi, tetapi kekuatan yang diperoleh tidak melebihi campuran konkrit kawalan. Pengaruh kemasukan silika ke atas keliangan dan penyerapan air konkrit kekuatan tinggi yang mengandungi isipadu tinggi sanga adalah dengan ketara mengurangkan kedua-dua keliangan dan penyerapan air khususnya pada kandungan isian silika yang lebih tinggi dan tempoh pengawetan yang

lebih lama. Keputusan menunjukkan bahawa konkrit yang mengandungi 20% wasap silika mencatatkan nilai kemerosotan 13 mm, dengan ketumpatan 2544 kg / m^3, kekuatan mampatan 76.03 MPa, keliangan 5.29% dan penyerapan air 3.23% pada usia 56 hari.

ABSTRACT

The use ground granulated blast furnace slag in concrete is advantageous from economic, environmental and technical points of view. However, the use of slag especially in high volume may negatively affect the strength and other properties of concrete. Therefore, this study explores the feasibility of using silica fume as partial replacement of slag in high strength concrete containing high volume of slag. A control high strength concrete mix was proportioned to have a 28 days strength of 70 MPa. A similar mix was proportioned but 60% of the ordinary Portland cement was replaced with slag on mass-for-mass basis. Further, another four concrete mixes were proportioned by partially replacing the slag content with silica fume at 5, 10, 15 and 20%. The effects of the incorporation of silica fume on workability, density, compressive strength, porosity and water absorption of the concrete were investigated. The results exhibit that the use of slag in combination with silica fume tends to reduce the workability of the high strength concrete. Concrete mixes containing slag as well as combination of slag and silica fume exhibit higher density than the control concrete. The inclusion of silica fume improves the strength of the high strength concrete containing high volume of slag, in particular at higher silica fume content, but the strength obtained does not exceed that of the control concrete mix. The influence of silica fume inclusion on porosity and water absorption of the high strength concrete containing high volume of slag is to significantly reduce both porosity and water absorption in particular at higher silica fume content and longer curing period. The results show that concrete containing 20% silica fume registers a slump value of 13 mm, with density of 2544 kg/m^3, compressive strength of 76.03 MPa, porosity of 5.29% and water absorption of 3.23% at the age of 56 days.

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LIST OF ABBREVIATIONS

SF	:	Silica fume
GGBS	:	Ground granulated blast-furnace slag
OPC	:	Ordinary Portland cement
BS	:	British Standard
ASTM	:	American Society for Testing and Materials
SCM	:	Supplementary cementitious material
HSC	:	High strength concrete

CHAPTER 1

INTRODUCTION

1.1 Background

New development has always been planned and initiated either to increase the number of economic gateway or for upgrading the available infrastructure. With the increase in construction activities will subsequently increase the demand for construction materials. The famous materials in the construction industry include cement and aggregate.

Ordinary Portland cement has been widely used throughout the world for its ability to act as a binder with other materials, harden and gain strength. While crushed rock aggregate is mainly used as aggregate in concrete in order to enhance its mechanical properties and also acts as reinforcement in the composite material.

But, apart from all the positive contributions of these material in particular Portland cement to the world of construction, there is also negative impacts that have been brought together with this type of material especially towards the environment. These negative impacts have been realized with regards to their potential disastrous effect in particular on the global climate change which has been a main issue across the world.

Because of the need of this material is still important in the world, suitable effort has to be made to find alternative or to produce materials that have the same properties with cement and natural aggregates but at the same time can reduce the negative impacts of their production to the environment. One of the alternative is by using wastes and by-products from industry.

Studies on utilization of industrial waste in construction has been done for several years. In the countries that have abundant of industrial waste production, these wastes may have the potential to partially replace cement or aggregates in the concrete industry. Many steel plants have been set up in our country. The function of this slag is to refine the steel of sulphur and to absorb the oxides formed as a result of deoxidation during steel production. Steel making slags are composed principally of calcium silicates, calcium aluminoferrites, and fused calcium oxides, iron, magnesium, and manganese (Karthik and Doraikkannan, 2015).

Silica fume is a by-product in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area in the order of 215,280 ft^2/lb (20,000 m^2/kg) when measured by nitrogen adsorption technique, with particles approximately one hundredth the size of the average particle size of cement and because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material. During the last decade, considerable attention has been given to the use of silica fume as a partial replacement of cement to produce high-strength concrete (Mallick, 2010).

Research and the utilization of micro silica as a pozzolanic material has increased in the recent years because when mixed in definite proportions it improves the properties of both fresh and hardened concrete like durability, permeability and compressive strength, flexural strength and tensile strength (Kumar et al., 2017).

Therefore, this research is expected to give some alternative or breakthrough to overcome the current problem of the concrete industry and its environmental problems. By utilizing the high volume of waste and by-product materials from the large scale of waste industry, it might also alleviate the problem of concrete limited natural resources of material in the future. By the way, this research will identify how the properties of concrete are affected when using steel slag and silica fume in the concrete mix.

1.2 Problem Statement

It is noticeable that the use of OPC can give harmful effects to the environment. So, to reduce the negative effects with OPC production to the environment, an alternative binder is proposed. The use of high volume of steel slag in concrete mixture will affect the early strength of the concrete. Thus, to overcome this problem, silica fume is added since it is a reactive pozzolanic material. The use of mineral admixtures can reduce the environmental contamination problem because they are sourced from industrial wastes or by-product materials.

1.3 Aim and Objectives

The aim of the study is to compare the effects of utilizing silica fume in combination with steel slag on properties of high strength concrete. The specific objectives are as the followings: -

1. To investigate the effect of slag and silica fume inclusion on workability of high strength concrete.
2. To evaluate the influence of silica fume inclusion on properties of high strength concrete containing high volume of steel slag in term of strength, density, porosity and water absorption.

1.4 Scope of Work

This study will focus on assessing the potential of steel slag and silica fume as supplementary binder material in high strength concrete. The high strength concrete will have partial replacement of Ordinary Portland Cement with combination of steel slag and silica fume replacement at (60, 55, 50, 45, and 40) % and (0, 5, 10, 15, and 20) %, respectively. While the other parameters such as water to binder ratio, fine and coarse aggregates are kept constant throughout the control and sample mixes. The performance of each mix in terms of compressive strength, density, permeability and porosity will be compared and discussed.

1.5 Layout of Dissertation

This dissertation consists of five different chapters. Chapter 1 introduces the research background, problem statement, objectives and scope of work. Chapter 2 presents the literature review involved. Chapter 3 explains the research methodology undertaken to achieve the research objectives. Chapter 4 shows the research results and discussion and Chapter 5 outlines the research conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The use of concrete is increasing day by day, so our natural resources may become depleted faster due to the increasing production of concrete. In order to reduce the rate of extraction of the natural resources and to reduce the associated environmental problem linked with cement and concrete industry, the use of by-product-based materials is a good option. Various studies have been carried out for the replacement of cement and aggregate and some of the literatures in this area dated from early 1980's. More recently strict environmental pollution controls and regulations have produced an increase in the industrial wastes and sub graded by-products which can be used as supplementary cementitious materials (SCMs) such as silica fume and steel slag. The use of SCMs in concrete constructions not only prevents these materials to exacerbate the environmental pollution but they are also able to enhance the properties of concrete in the fresh and hardened states (Karthik and Doraikkannan, 2015).

Steel slag is the residue of steel production process and composed of silicates and oxides of unwanted elements in steel chemical composition. Fifty million tons per year of slag were produced as a residue from Basic Oxygen Process (BOP) in the world (Ravinder, 2017). Steel slag, which is considered as the strong waste poison, can be utilized for street development, clinker crude materials, filling materials, and so on. Steel is fundamentally a composite of iron and carbon containing under 2% carbon and 1% manganese and little measures of silicon, phosphorus, sulfur and oxygen (Abrol et al., 2016).

Mineral admixtures, also known as cement replacement materials, act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened cement matrix becomes denser and stronger with the utilization of mineral admixtures. Silica fume improves the properties by pozzolanic reaction and by reactive filler effect. Industrial by-products such as silica fume, bottom ash and steel slag aggregate improve the engineering and performance properties of high performance concrete when they are used as a mineral additive or as partial raw material replacement (Subbulakshmi and Vidivelli, 2016).

The main benefits of SCM's are their ability to replace certain amount of cement and still able to display adequate cementitious property, thus reducing the cost of using Portland cement. The fast growth in industrialization has resulted in tons and tons of by-product or waste materials, which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag, steel slag etc. The use of these byproducts not only helps to utilize these waste materials but also enhances the properties of concrete in the fresh and hardened states (Patel and Charkha, 2012).

2.2 Silica Fume

Silica fume is a by-product of the manufacture of silicon metal and ferro-silicon alloys. The process involves the reduction of high purity quartz (SiO_2) in electric arc furnaces at temperatures in excess of 2,000°C. Silica fume is a very fine powder consisting mainly of spherical particles or microspheres of mean diameter of about 0.15 microns, with a very high specific surface area (15,000–25,000 m^2/kg). Each microsphere is on average 100 times smaller than an average cement grain. At a typical dosage of 10% by mass of cement, there will be 50,000–100,000 silica fume particles per cement grain (King, 2012).

2.3 High Strength Concrete

The fundamental parameters to produce high strength concrete are low porosity which is achieved by including cement contents in excess of 500 kg/m^3, good quality and well-graded aggregates, low water/cement ratios (expected to be less than 0.35), and adequate compaction and curing. The advantage of high-strength concrete is that, structural members or sections are reduced in size and consequently increasing the required space in concrete structure and volume of concrete- making materials are reduced (Eren and Çelik, 1997).

High strength concrete has been widely used in civil engineering applications in the recent years. This is because most of the rheological, mechanical, and durability properties of these materials are better than those of conventional concretes. High strength is made possible by reducing porosity, inhomogeneity and microcracks in concrete and improving the transition zone. This can be achieved by using superplasticizers and supplementary cementing materials such silica fume, granulated blast furnace slag, and natural pozzolan (Shannag, 2000).

2.4 Steel Slag

Steel slag is an industrial by-product obtained from the steel manufacturing industry. It is a non-metallic ceramic material formed from the reaction of flux such as calcium oxide with the inorganic nonmetallic components present in the steel scrap (Thangaselvi, 2015). Quality assessment of ecofriendly concrete that is made out of cement and steel slag as coarse aggregate, steel slag as fine aggregate and some quantity of fly ash has been carried out. This will solve the problem of waste disposal, while at the same time preserving our natural resources (Abrol et al., 2016).

The fast growth in construction has resulted in the generation of tons and tons of by-products or waste materials, which can be used as SCMs such as fly ash, silica fume, ground granulated blast furnace slag, steel slag, etc. The use of these by-products not only helps to utilize these waste materials but also enhances the properties of concrete in the fresh and hardened states (Krishna and Kumar, 2016). Steel slag has high specific gravity, high abrasion value than naturally available aggregate apart from the drawbacks like more water absorption and high alkalis (Mallick, 2010).

2.5 Curing

The objective of curing is to keep concrete saturated, or as nearly to saturated, to get the products of hydration of cement to be developed in the water-filled spaces. Proper curing is one important measure to get durable concrete. In practical aspects, most of the concretes used in laboratory investigations are cured in potable water for up to 28 days or much longer. Nonetheless, most curing techniques used at construction sites currently have many practical drawbacks. Plastic wrappers around the concrete are seen to be a good curing method. Concrete immersed in water is the closest method to the laboratory curing method. Spraying of water on the concrete surface at sites is the usual method adopted in the field (Mannan and Ganapathy, 2001).

2.6 Summary

The literature review indicates the necessity of using high cement content and natural aggregates to produce concrete in the future which could implicate a higher cost and environmental problems. The high strength concrete using combination of steel slag and silica fume which is a renewable material compared to normal concrete have a potential for reducing the OPC usage as it shows an adequate strength development. While the potential of steel slag and silica fume as a mineral admixture for concrete has been shown to be suitable, however, best ratio of both is required to increase its pozzolanic property. Thus, the present research aims at exploring the potential of steel slag and silica fume as a supplementary binder for high strength concrete. Many works have been done to explore the benefits of using pozzolanic materials in making and enhancing the properties of concrete. The effect of steel slag and silica fume on compressive and fracture behaviors of concrete had concluded enhancement in strength properties of concrete by adding different percentage of steel slag and silica fume. Thus, this research study aims to compare the effect of utilizing silica fume in combination with steel slag on properties of high strength concrete in term of workability, strength, density, porosity and water absorption.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, the methodology to achieve all the objectives stated in Chapter 1 such as density, porosity, permeability and compressive strength will be explained. The steps of preparing mix design required using material such as steel slag and silica fume for the mixing purpose will be provided further. The testing method that will be followed throughout the test are based on American Society for Testing and Materials (ASTM) and British Standard (BS) test procedures.

3.2 Experimental Design

The overall stages of the research work undertaken in this study is shown in Figure 3.1 below.

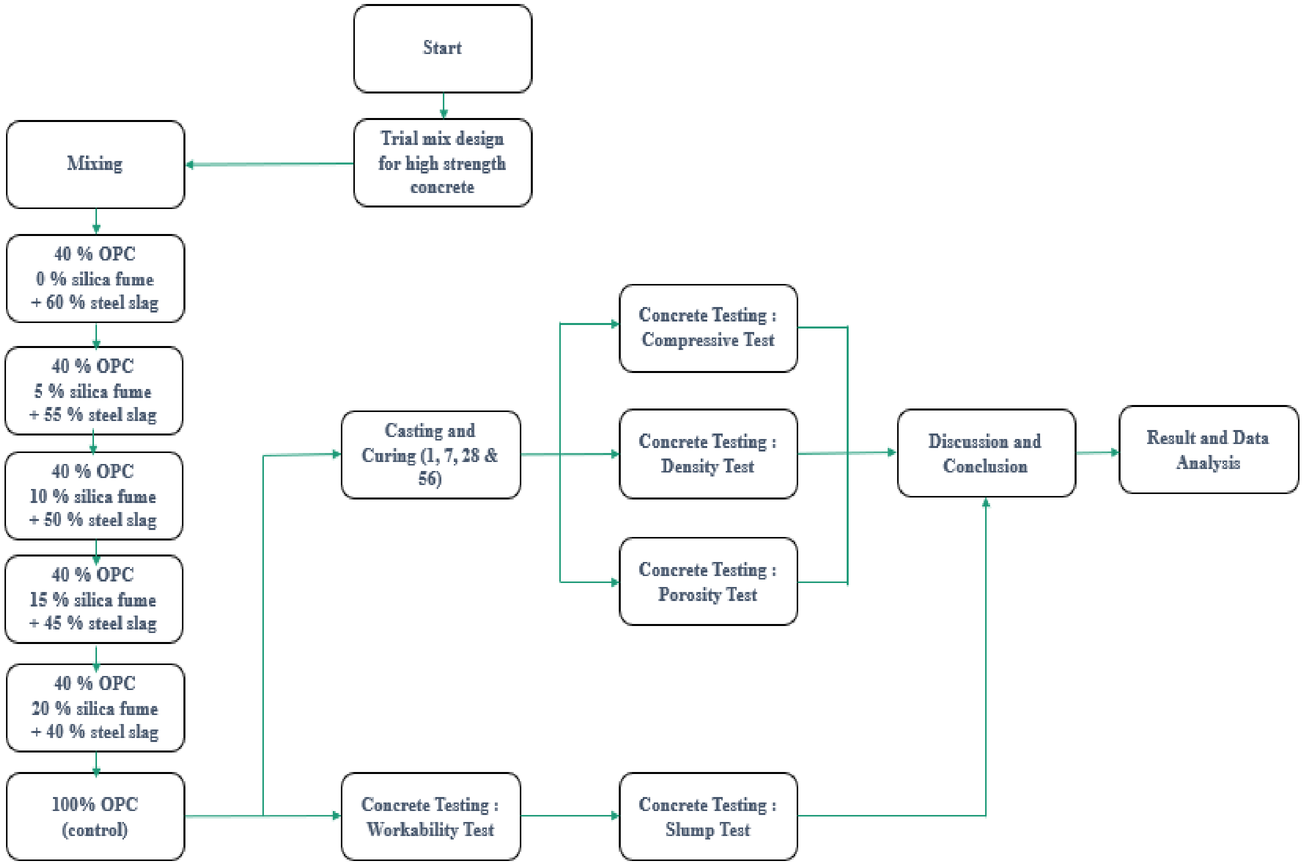

Figure 3.1 Overall stages of research work

3.3 Materials

The materials used to produce the high strength concrete mixes in this research include:

-

i. Ordinary Portland Cement (OPC),
ii. Local river sand
iii. Crushed granite aggregate
iv. Water
v. Silica Fume
vi. Steel Slag
vii. Superplasticizer

3.3.1 Ordinary Portland Cement

Figure 3.2 shows the cement used in this research which was Ordinary Portland cement (OPC), which conformed to BS EN 197-1. Care was exercised to ensure that the cement used did not exceed the period of storage for three months after production.

Figure 3.2 Ordinary Portland cement used in this study

3.3.2 Aggregates

The fine aggregate used in this study was local river sand with size passing sieve 2.36 μm while coarse aggregates were from crushed granitic rock with maximum size of 20 mm obtained from a nearby quarry.

3.3.3 Water

Tap water from the domestic water supply source available in the Concrete Laboratory was used as concrete mixing water throughout the study.

3.3.4 Silica fume

Figure 3.3 shows the silica fume used in this study. Silica fume is by-product from the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements are obtained from the addition of a very fine powder which acts as filler to the cement paste, as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste (Harish and Supriya, 2015).

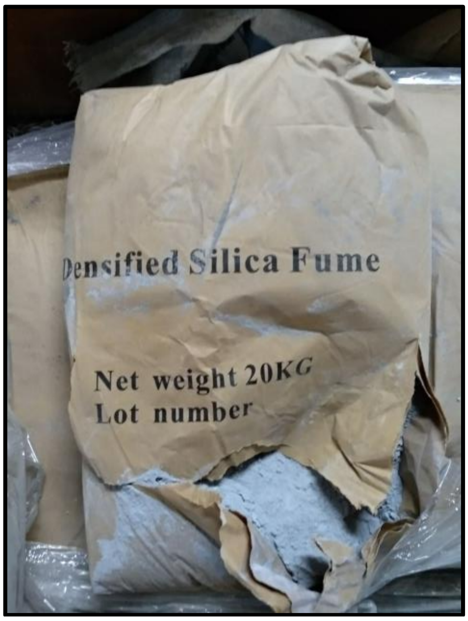

Figure 3.3 Silica Fume

3.3.1 Steel slag

Figure 3.4 shows the steel slag used in this study. It is a by-product of steel making, generated during the separation of molten steel from impurities in steel making furnaces. Steel is fundamentally a composite of iron and carbon containing under 2% carbon and 1% manganese and little measures of silicon, phosphorus, sulfur and oxygen.

Figure 3.4 Steel Slag

3.3.5 Superplasticizer

Figure 3.5 shows the MasterGlenium ACE 8109 superplasticizer produced by BASF Group which was used in the concrete mix to obtain adequate workability. It is a high-range water reducing admixture. The use of this superplasticizer allows the reduction of the water to cement ratio and not affecting the workability of the mixture. The amount of the superplasticizer that was used in the concrete mix was 1.25% from the mass of the binder content.

Figure 3.5 MasterGlenium ACE 8109 superplasticizer

3.4 Mix Proportions

A total of six high strength concrete mixes were prepared in this study. The control mix (Mix 1) was prepared using 100% OPC and proportioned to have a 28-day characteristic strength of 73 MPa. The combination of binder was used to partially replace the OPC by mass and the water to cementitious material ratio was set at 0.315. The dosage of superplasticizer used in all mixes is 1.25%. The other five mixes were prepared with the same proportion, but 60% of the OPC content was replaced with either steel slag or steel slag in combination with silica fume. Mix 2 was prepared with steel slag replacing 60% of OPC, while Mix 3, Mix 4, Mix 5 and Mix 6 were prepared with steel slag content of 55, 55, 45 and 40 % as well as silica fume content of 5, 10, 15 and 20 %, respectively. Table 3.1 shows the mix proportions of the concrete mixes.

Table 3.1 The mix proportions of the concrete

Concrete Mix	Mix	Batched Quantities (kg/m^3)						
		OPC	Water	Fine	Coarse	SS	SF	SP
Mix 1	100 % OPC	540	170	465	1246	-		6.75
Mix 2	40 % OPC,60 % SS, 0% SF	216	170	465	1246	324	-	6.75
Mix 3	40 % OPC,55 % SS, 5% SF	216	170	465	1246	297	27	6.75
Mix 4	40 % OPC,50 % SS, 10% SF	216	170	465	1246	270	54	6.75
Mix 5	40 % OPC,45 % SS, 15% SF	216	170	465	1246	243	81	6.75
Mix 6	40 % OPC,40 % SS, 20% SF	216	170	465	1246	216	108	6.75

3.5 Mixing, Casting and Curing

The laboratory work for mixing method of the concrete material such as the time and condition of mixing of materials is explained in this section. The step for casting the concrete mix into the moulds and the curing processes are also discussed.

3.5.1 Samples Preparation

Table 3.2 shows the number of samples for each mix for the difference tests. For every mix, the samples need to be cast into 12 cubes with dimensions of 100 mm x 100 mm x 100 mm for compressive strength test along with density test, and 2 prisms with dimensions of 100 mm (height) x 100 mm (width) x 500 mm (length) for the porosity and water absorption tests. For porosity and water absorption, the cylindrical samples were prepared with the dimensions of 40 mm (height) x 50 mm (diameter) by coring and cutting of the hardened concrete beam samples with dimensions of 100 mm x 100 mm x 500 mm which were cast along with the cube and cylindrical samples.

Table 3.2 Number of samples for the different tests

Concrete Mix	Compressive Strength Test	Density Test	Porosity & Water Absorption Tests
Mix 1	12	12	12
Mix 2	12	12	12
Mix 3	12	12	12
Mix 4	12	12	12
Mix 5	12	12	12
Mix 6	12	12	12

3.5.2 Mixing

The mixing of the concrete started with pouring the sand and coarse aggregate into the concrete mixer and mixing the materials in dry condition for 1 minute. Then, the cement was spread and dry mixed for 1 minute. After that, water and superplasticizer were added in half and mixed for 3 min and continued mixing for 5 minutes with another half. Slump test was performed on the concrete mixture prior to casting the samples. Figure 4.6 shows the mixing process before the addition of water.

Figure 3.6 Dry mixing of concrete prior to addition of water

3.5.3 Casting and Curing

The concrete mix was placed into the relevant moulds in three layers, where for each layer the samples were vibrated using vibrating table to remove entrapped air. Then the samples were left to harden. After 24 hours, the samples were demolded. All specimens were cured in water at room temperature after the first day of production until the testing date. Photo of the samples after casting is shown in Figure 3.7, while photo of the samples being cured in curing tank is shown in Figure 3.8.

Figure 3.7 Casting of fresh concrete

Figure 3.8 Concrete samples under curing

3.3 Testing Procedures

This section will explain about the methods used to test the concrete samples to obtain the required information for the further analysis.

3.3.1 Workability Test

Workability of the concrete mixes was assessed by the means of the slump test according to BS EN 12350-2:2009. The concrete slump test is an empirical test that measures the workability of fresh concrete. It measures the consistency of the concrete in that specific batch mixes. This test is performed to check the consistency of freshly made concrete. Consistency is a term very closely related to workability. It refers to the ease with which the concrete flows and consolidates. The slump was determined by measuring the different between the height of the mould and the highest point of the slumped test samples. The apparatus used for the slump test is shown in Figure 3.9.

Figure 3.9 The slump test apparatus

3.3.2 Compressive Test

The compressive strength test was conducted to determine the compressive strength of the concrete mix using the compressive strength testing machine (Figure 3.10) in the laboratory. This test was conducted on cube samples at 1, 7, 28 and 56 days. This test was conducted according to ASTM C109/ C109M by using a 3000 kN concrete compression machine. In this test, cube samples with the dimension 100 mm x 100 mm x 100 mm were used. The maximum load measured by the testing machine was recorded, and the compressive strength of the sample was calculated based on Equation 3.1 below.

$$F = \frac{P}{A} \tag{3.1}$$

Where;

F = Compressive strength (MPa)

P = Maximum load (N)

A = Area of loaded surface (mm^2)

Figure 3.10 Compressive strength testing machine

3.3.3 Porosity and Water Absorption Tests

Porosity test was conducted to measure the air void content in the concrete sample. The test sample size of 50 mm (diameter) x 40 mm (thick) was obtained by coring and then oven drying at 105°C for 24 hours to get the dry weight (W_4) of the samples. The samples were then placed in the vacuum saturation apparatus and applied with vacuum pressure of one bar for 3 hours. While the samples were still under vacuum, they were submerged with water so that about 1 cm of water covering the top of the samples. The vacuum was maintained for another 3 hours. After that, the vacuum was released, and the samples were kept submerged in water for about 1 further hour to achieve full saturation. Then, the samples were taken out and their surfaces were wiped with dry cloth before taking the weight in air (W_2) and in water (W_3). Figure 3.11 shows the core samples for porosity and water absorption tests while Figure 3.12 shows the vacuum desiccator used in the tests. The water absorption (A) and porosity (P) were determined using Equation 3.2 and Equation 3.3, respectively.

Water absorption (A);

$$A\ (\%) = \frac{W2-W4}{W4} \times 100 \qquad (3.2)$$

Porosity (P);

$$P\ (\%) = \frac{W2-W4}{W2-W3} \times 100 \qquad (3.3)$$