EFFECT OF SILICA FUME ON THE PROPERTIES OF HOLLOW CONCRETE BLOCK

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By

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ABSTRAK

Blok konkrit telah mula digunakan dalam industri pembinaan sejak awal abad ke 20. Ia dijadikan sebagai bahan isian untuk pembinaan dinding dan juga sebagai bahan penampung beban. Oleh kerana permintaan untuk blok konkrit di dalam industri pembinaan kini meningkat dan berkemungkinan akan terus meningkat di masa hadapan, kajian ini dilakukan untuk mencari sifat-sifat batu blok terutamanya batu blok berongga dengan bahan lain untuk memperbaiki kekuatan dan ketahanannya. Untuk kajian ini, blok konkrit berongga dengan tambahan wasap silika telah dibuat menggunakan nisbah reka bentuk campuran kering, 1:6. Ujian seperti ujian kekuatan mampatan, ketumpatan, serapan air dan kadar serapan air awal telah dijalankan untuk mencapai objektif kajian ini. Sebanyak 36 sampel telah dibuat untuk kedua-dua jenis blok konkrit iaitu blok konkrit biasa dan blok konkrit dengan wasap silika. Berdasarkan hasil dan pemerhatian daripada ujian yang dijalankan, kekuatan blok konkrit dengan wasap silika adalah lebih tinggi dari batu blok biasa sebanyak 50%. Peratus serapan air dan kadar serapan air awal juga lebih rendah dan blok konkrit dengan wasap silika juga lebih tumpat.

ABSTRACT

Concrete block has been commonly used in constructions since in the first half of the 20th century. The blocks are mainly used as fillers in wall constructions and also as load bearing units. Since the demand of concrete block is high on the market currently and possibly the future, this study is done to find the properties of concrete block especially hollow concrete block with other materials in order to enhance its performance and durability. For this research, hollow concrete block with an admixture of silica fume was formed by using a dry mix design ratio, 1:6. Tests such as compressive strength test, density test, water absorption test and initial rate of suction (IRA) were done to find the properties of the block and to compare them to the control block that was also created by using the same dry mix design ratio but without any admixture. A total of 36 samples were produced for both the control block and the block with silica fume. The properties of the hollow concrete blocks were taken based on the testing results. From the results and observations, the strength of the hollow concrete block with silica fume was enhanced and higher than the control block by approximately 50%. The water absorption and initial rate of suction of the silica fume concrete block were also lower than the control, and the blocks were much denser.

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LIST OF ABBREVIATIONS

AAC: Aerated Autoclave Concrete Block

ASR: Alkali-Silica Reaction

ASTM: American Society for Testing and Materials

AASHTO: American Association of State Highway and Transportation Officials

BS: British Standard

CH: Calcium Hydroxide

CSH: Calcium Silicate Hydrate

CMU: Concrete Masonry Unit

ISO: International Organisation of Standardisation

SF: Silica Fume

CHAPTER 1

INTRODUCTION

1.1 Background Overview

Concrete block is primarily used as a building material in the construction of walls and is also known as concrete masonry unit (CMU). It is among the pre-cast concrete products used in construction. Pre-cast concrete blocks are the blocks that are formed and hardened before they are brought to the job site. Most of the concrete blocks have one or more hollow cavities, and their sides may be cast with pattern or smooth. The concrete blocks are constructed by stacking them one at a time and held together with fresh mortar according to the desired length and height of the wall.

Throughout history, the use of mortar was recorded by the Romans in the 200 B.C. to connect shaped stones together to form various buildings. Majority of the concrete technology developed by the Romans was lost after the fall of the Roman Empire in the fifth century. However, in 1824 an English stonemason Joseph Aspdin developed Portland cement, which became one of the key components of modern concrete.

According to Hornbostel (1991), the first hollow concrete block was invented in 1890 by Harmon S. Palmer in the United States. Palmer patented the design in 1900 after 10 years of experimenting and the blocks were 8 in (20.3 cm) by 10 in (25.4 cm) by 30 in (76.2 cm), and were very heavy that they had to be lifted into place with a small crane.

These early blocks were usually cast by hand, and the average output was about 10 blocks per person per hour. While for the current time, concrete block manufacturing is a highly automated process that can produce up to 2,000 blocks per hour. Although the first blocks were manufactured by hand, nowadays they are produced in an automated way and thousands of blocks can be made per hour.

There are several types of concrete blocks that are available for construction. For instances, the hollow concrete block as shown in Figure 1.1, the aerated autoclaved concrete block (AAC) as shown in Figure 1.2, concrete bricks, solid concrete block, the lintel block, the paving block as shown in Figure 1.3, and the concrete stretcher block.

Figure 1.1 Hollow Concrete Block

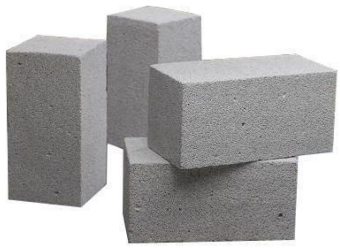

Figure 1.2 Aerated Autoclaved Concrete Block (AAC)

Figure 1.3 Paving Block

The hollow concrete block is the most commonly used concrete block in construction. Concrete hollow block is usually consisted of lightweight aggregates with a certain design load depending on its uses and it generally has voids quarter of its gross area and the solid area should be not less than half of its area to attain its maximum allowable load capacity as study suggests.

It has the characteristics that ease the consumer such as the prominent hollow cores that reduces the weight of the block. The cores comprise air pockets which make it a very good for heat insulation and the block is also good for acoustics and sound insulation. The rough surface allows good bonding between the concrete blocks and the mortar, the internal walls can also be thinner in thickness as it is very strong and the resistance against external weather conditions is good.

Silica fume is a well-known mineral admixture composed of sub-micron particles (100 to 150 times smaller than a grain of cement) of amorphous silicon dioxide. It is used in cementitious applications (concrete, shotcrete, repair products and oil well grouts) as both a filler - improving the physical structure by occupying the spaces between the cement particles - and as a “pozzolan” reacting chemically to impart far greater strength and durability to concrete, Silica Fume Association (2014).

This admixture is chosen to increase the strength and the durability of the concrete, as well as to decrease the permeability of the concrete, and it gives concrete integral protection from damage by chemicals including sulphate attack and alkali-silica reaction (ASR).

1.2 Problem Statement

Concrete block is primarily used in building construction throughout the years until now. In the current time, tons of new technology are in the market and they have become strong competitors for concrete blocks in construction. However, concrete block is still valued for its aesthetic values, strength and eco-friendly environment for the users.

So in this project, hollow concrete block with the addition of silica fume as partial cement replacement is produced. This is to create a stronger hollow concrete block with good properties. It is also to create a greener materials for building by using materials like Silica Fume which is a by-product of silicon and ferrosilicon alloy production. The comparison between hollow concrete block with silica fume and the ordinary hollow concrete block in terms of properties will be studied. This study is mainly for research purpose.

Silica fume is used because it gives high early strength, high tensile and flexural strength as well as its permeability to chloride and water intrusion is very low for the concrete block.

1.3 Objectives

The objectives of this study are:

1. To determine the properties of hollow concrete block with silica fume.
2. To evaluate and compare the differences in properties between ordinary hollow concrete block and hollow concrete block with silica fume.

1.4 Scope of Study

This research was aimed to study the properties of concrete block with silica fume. The main properties of the concrete block that will be tested were the strength, density, permeability and water absorption. This study will be carried out experimentally by comparing the results from the tests between hollow concrete block added with silica fume and the ordinary hollow concrete block without any admixture.

The compressive strength test was done to conclude the strength of the concrete block especially with a partial cement replacement of silica fume. For the determination of its density and the dimension of the block, their respective tests were carried out suitably. The results from these tests were used to compare ordinary concrete block and concrete block with silica fume to determine their level of quality.

The final outcome of this study was to determine the quality and strength of concrete block with 5% silica fume as cement replacement, as well as to compare its properties in juxtaposed to ordinary concrete block. The strength of the concrete block was the focus among the other properties as stated previously.

1.5 Dissertation Outline

The dissertation is divided into five chapters. The general description of the chapters are explained in this section.

Chapter 1: Introduction

This chapter is basically the general overview of the project's element which is the concrete block. The problem statement is included to summarise the purpose of carrying out this study. In order to solve the problem as stated, several objectives are set.

Chapter 2: Literature Review

This chapter is for the summaries of researches, reviews and journals related to the testing and mechanical properties of concrete block. Related past research works are discussed in details to assist in finding the correct testing, objectives and expected outcomes for this study.

Chapter 3: Research Methodology

This chapter explains the experimental works and tests done in order to retrieve the mechanical properties of the concrete blocks studied.

Chapter 4: Results and Discussion

This chapter presents the results, discussion and the overall achievement of the objectives of this study. Each data is justified and compared with the previous related researches.

Chapter 5: Conclusions and Recommendations

This chapter summarises the outcomes of this research and provides the appropriate recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter is focused on the reviews of previous works, researches and literatures on hollow concrete block and silica fume. The general informations regarding the background and properties of the elements of this study are explained.

2.2 Hollow Concrete Block

Concrete Masonry Units or CMU are also known as concrete blocks. The main composition of these concrete blocks are Portland cement and aggregate, the high density blocks may use sand and gravel while low density blocks use industrial waste instead of aggregate. The hollow concrete blocks are manufactured, hardened and cured before reaching the site to sustain its durability and strength.

Hollow concrete block are also in uniform sizes and consist of two hollow cores which make it good heat insulator due to the air pockets. Other advantages of using hollow concrete block in buildings include good sound insulation, economical and have rough surface texture that allow ease of bonding between the concrete block and mortar.

There are several types of concrete block as according to Short and Kinniburgh (1978), blocks are classified into two types, i.e composed of aggregate concrete and aerated concrete. For aggregate concrete block, it is divided into two groups as follows:

1. Those made from organic material, which is chemically stabilised sawdust or wood meal.
2. Those employing mineral aggregates.

Meanwhile the type of concrete blocks as stated in BS 2028 - part 1, are classified into three types, as follow:

1. Type A: Dense aggregate blocks with density of not less than 1500 kg/m^3.
2. Type B: Lightweight aggregate blocks for load bearing wall.
3. Type C: Lightweight aggregate blocks for non-load bearing partitions.

The type A density should be 1500 kg/m^3, while for type B and C the density should be between 650 kg/m^3 and 1500 kg/m^3.

In addition to the information above, according to Concrete Block Association UK (2017), hollow concrete block which is also known as the cellular blocks are masonry units that contain one or more voids that do not fully penetrate the block. Cellular blocks have significant advantages over solid blocks where weight is a prime consideration. The reduced unit weight makes for ease of handling, reduced floor/foundation loading, economic and efficient productivity. There are two block types which are:

1. Dense aggregate blocks (typical material density range 1800 kg/m^3 - 2100 kg/m^3)

2. Lightweight aggregate blocks (typical material density range 850 kg/m^3 - 1500 kg/m^3)

Typical shape of concrete blocks is shown as attached in Figure 2.1 and Figure 2.2 for additional references.

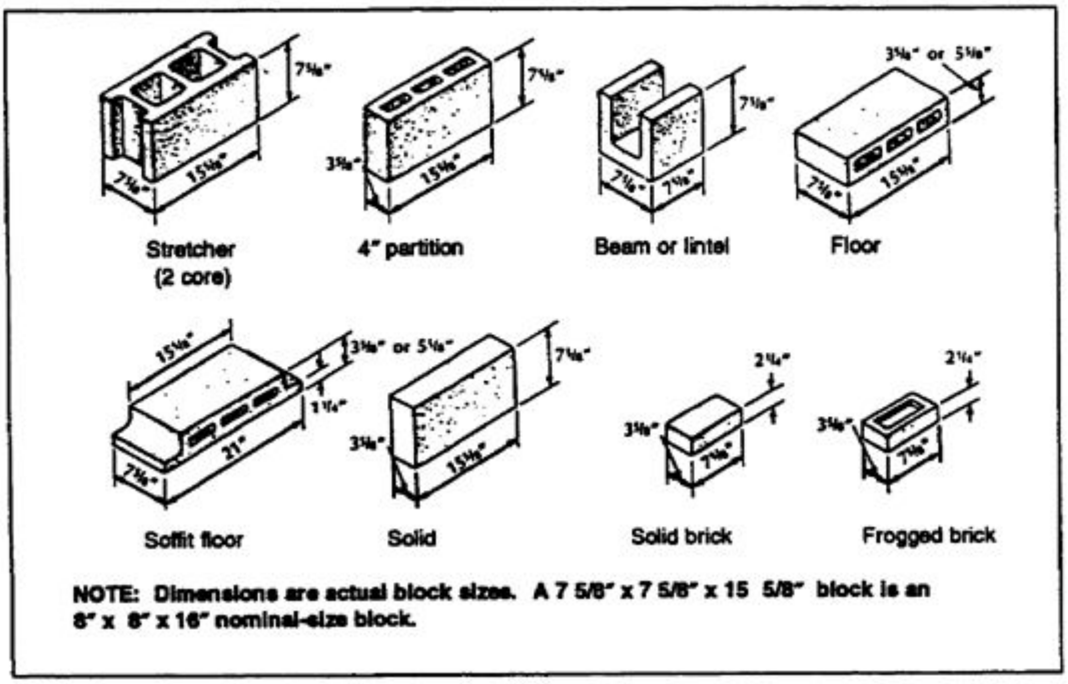

Figure 2.1 Typical shape of concrete blocks, taken from (http://waybuilder.net)

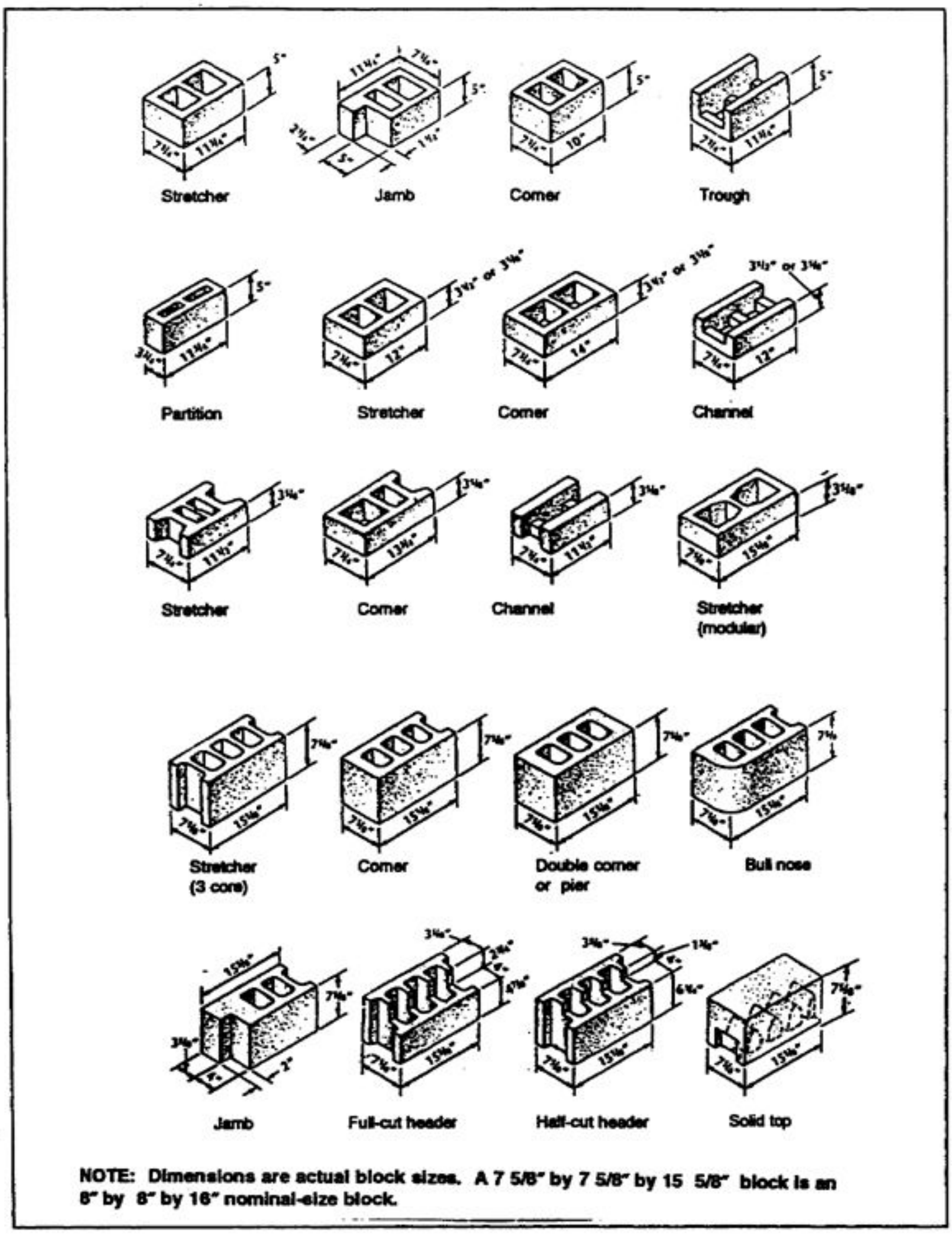

Figure 2.2 Typical shape of concrete blocks, taken from (http://waybuilder.net)

For the production of concrete block, dry mixing is used. The mixing must be done thoroughly due to low water cement ratio and to ensure that the mix is workable and practical. In terms of application, concrete blocks are generally applicable as block walls and retaining walls, flooring, traffic barrier, and others.

2.3 Silica Fume

Silica fume is a by-product of ferro-silicon and silicon metal and it is a very efficient pozzolanic material. It is often used as admixture and partial replacement of cement. Silica fume also conforms to ASTM C1240 - 15 requirements as a mineral admixture material. It is very efficient with concrete especially concrete with high water-cement ratio range from 0.55 and above. The chemical composition for silica fume generally contain more than 90 percent silicon dioxide, mostly amorphous. Other constituents are carbon, sulphur and the oxides of aluminium, iron, calcium, magnesium, sodium and potassium. The chemical composition of the fume varies based on the type of alloy or metal being produced. For example, the fume from a ferro-silicon furnace will generally contain more iron and magnesium oxides than that from a furnace producing silicon metal, V.M. Malhotra et. al (1982).

The physical properties of silica fume include having spherical particles shape with average particles size of 0.1µm, amorphous structure, high silicon dioxide (SiO_2) content and consists of high surface area of around 20 m^2/g, Nawy (2001). The pozzolanic reaction is when silica fume is added or replaced into cement, it acts as filler due to its fine size and chemically reacts with $Ca(OH)_2$ to improve the aggregate-cement pastes interface, which will enhance the concrete's durability and performance.

Applications of silica fume in concrete include to produce high strength and durability concrete, to conserve cement and to reduce alkali-aggregate reaction. Table 2.1 and Table 2.2 below shows the physical properties and chemical compositions of silica fume as taken from Tayeh et. Al (2013).

Table 2.1 Physical composition of silica fume

Properties	**Values**
Specific gravity	2.18
Specific surface area (m^2/g)	23.7
Median particle size (µm)	0.1 - 1

Table 2.2 Chemical compositions of silica fume

Components	Values (%)
SiO_2	92.6
Al_2O_3	0.89
Fe_2O_3	1.97
CaO	0.94
MgO	0.96
P_2O_5	-
K_2O	1.31
SO_3	0.33
TiO_2	0.25
MnO	0.11
C	0.07
LOI	4.96

2.4 Concrete Containing Silica Fume

Silica fume has been widely used as an admixture or partial cement replacement material. Overall efficiency of silica fume is not constant at all replacement percentages (3-40%), Ghanesh Babu et. al (1995). When it is added to concrete, it will initially remains inert. Once the hydrating process occurred, primary chemical reactions produced two chemical compounds; Calcium Silicate (CSH) which is the strength producing crystallisation and Calcium Hydroxide (CH) which is a by-product (free lime) that is responsible for lining available pores within concrete as filler. The pozzolanic reaction occurred between silica fume and CH produced an additional CSH in the voids around hydrated cement particles. CSH improves compressive, flexural and bond strength of the concrete as well as creates a denser matrix mostly in areas that would have remained as small voids, subject to possible ingress of deleterious materials.

Silica fume can cause significant changes in the paste matrix micro-structure, but is not effective in enhancing the concrete paste strength. The most important activity of silica fume is its micro-filler effect, expressed in filling and densification of the transition zone, followed by the enhancement of concrete strength, due to a composite material effect, Goldman et. al (1993). Incorporation of silica fume is also statistically proved to be effective on the mechanical properties of concretes, Güneyisi et. al (2013).

In terms of compressive strength and tensile strength according to Bhanja et. al (2005), inclusion of silica fume improves tensile strength of concrete as well as compressive strength. Optimum silica fume replacement percentages for 28-day split tensile strength is in the range of 5-10%. Split and flexural tensile strengths at 28 days is about the same trend as 28-day compressive strength. More than 15% silica fume replacement is insignificant to increase split tensile strength. Sizeable gains in flexural tensile strength have occurred up to 25% silica fume replacement. The use of silica fume in concrete mixes increases the compressive strength of concrete is further proven in Qureshi et. al (2018).

Based on Mazloom et. al (2004), compressive strength development of concrete containing silica fume was negligible after the age of 90 days but have 26% and 14% strength increases in the control concrete after one year compared to at age 28 and 90 days. Strength development in OPC concrete and silica fume concrete can be attributed to rapid formation of an inhibiting layer of reaction product preventing further reaction of silica fume with calcium peroxide after 90 days. Inclusion of silica fume also decreases moisture movement on the first wetting cycle. Silica fume does not affect shrinkage and it happens in concrete due to hydration occurring during wet storage that leads to chemical and physical bonding.

The increase in water-binder ratio also reduces the compressive strength of concrete irrespective of the use of silica fume. Silica fume has no noticeable effect on the splitting tensile strength of concrete. The resistance against chloride ion penetration increases with the increase in the contents of silica fume in concrete. A reduction in water-binder ratio increased the ability of the concrete to resist chloride ion's penetration. The introduction of silica fume in concrete reduces the water absorption capacity of concrete. A change in water-binder ratio also dramatically reduces the water absorption of concrete, Qureshi et. al (2018).

2.4 Summary

This chapter provides details on silica fume and concrete block based on past studies. The compatibility of using silica fume as partial cement replacement in concrete block and its effects on mechanical properties are studied. The partial cement replacement of silica fume in concrete has been proven to improve compressive strength and other properties.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

In this chapter, the methods used to fulfil the objectives stated for this study are explained. This include the preparing stage of the ordinary concrete block samples and concrete block with silica fume samples. The respective tests that are carried out are aligned with the requirements from British Standard (BS), Malaysian Standard (MS), American Society for Testing and Materials (ASTM) and International Organisation of Standardisation (ISO) test procedures.

3.2 Experimental Design

The research methodology is summarised as below in Figure 3.1.

3.3 Materials

The list of materials used for preparations of ordinary concrete block samples and concrete block with silica fume samples:

1) Ordinary Portland Cement (OPC)
2) Silica fume
3) Fine aggregate (River sand)
4) Water

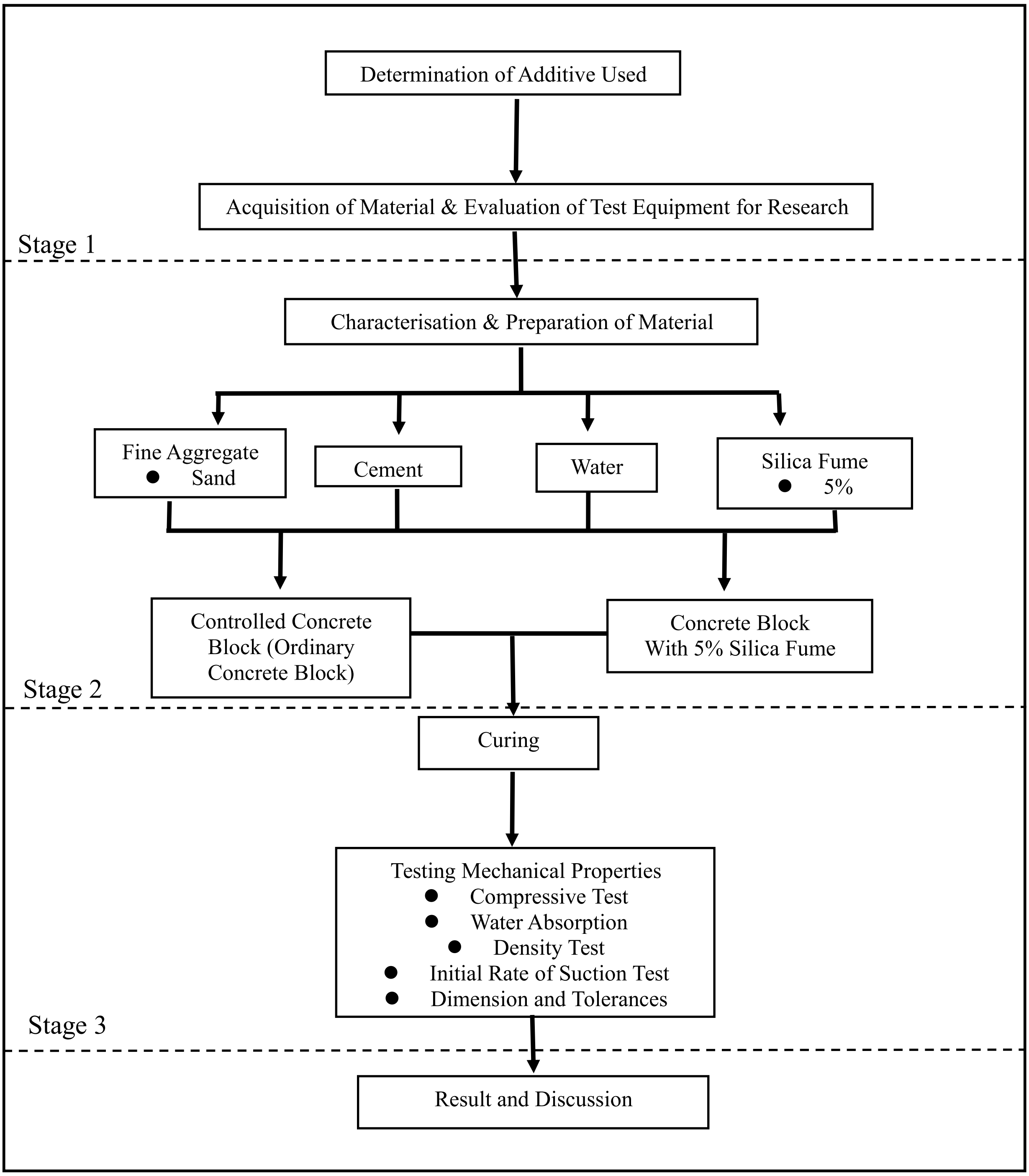

Figure 3.1 Flow chart of research methodology

3.3.1 Ordinary Portland Cement

The use of Ordinary Portland Cement (OPC) as the binder for concrete mixes in this study complied with ASTM C150/C150M (2009) and BS-EN 197-1. The cement is manufactured at Tasek Corporation Berhad.

3.3.2 Silica Fume

The main function of Silica Fume (SF) is to enhance the strength of the concrete. It is used as the cement replacement by 5% of the concrete block with silica fume samples, as both a filler - improving the physical structure by occupying the spaces between the cement particles - and as a "pozzolan" reacting chemically to impart far greater strength and durability to concrete. The SF used has more than 92% of silicon dioxide, SiO_2 content, specific gravity of 2.18 and surface area of 23.7 m^2/g. It conformed to ASTM C1240 - 15.

3.3.3 Fine Aggregate (River Sand)

River sand is used as the fine aggregate for the concrete block. It has been washed to remove impurities. The sand met the requirement of ASTM C136 (ASTM, 1996b).

3.3.4 Water

Tap water available at USM concrete lab is used in the concrete mixes. The source is from a domestic water supply.

3.4 Mix Design and Proportions

The dry mix ratio 1:6 of cement-sand by volume, is adopted for both ordinary concrete block and concrete block with silica fume. The difference is only on the 5% cement replacement of SF in the latter. Approximately two portions of the mix are needed to form one concrete block. The ordinary concrete block is set as the control with normal characteristics and strength at 28 days. Table 3.1 below depicts the mix proportions for one hollow concrete block.

Table 3.1 Mix proportions

Mix	Per concrete block (kg/m^3)			
	OPC (kg)	Sand (kg)	Silica fume (kg)	Water (l)
Ordinary concrete block	2.00	12.00	-	1.00
Concrete block with SF	1.90	12.00	0.10	1.00

3.5 Mixing, Casting and Curing

The proper methods of mixing, casting and curing the concrete block are discussed in this section. The steps of casting the concrete block by using the manual hydraulic pressing machine is also explained further.

3.5.1 Sample Preparations

The total number of 36 concrete blocks with the dimension of 9.5 cm x 20 cm x 40 cm are required in each type of block for compressive strength test, water absorption test, density test, initial rate of suction test and dimensions and tolerances test. The dimension of the concrete block is shown in Figure 3.2. The number of concrete block samples according to the tests is shown in Table 3.2.

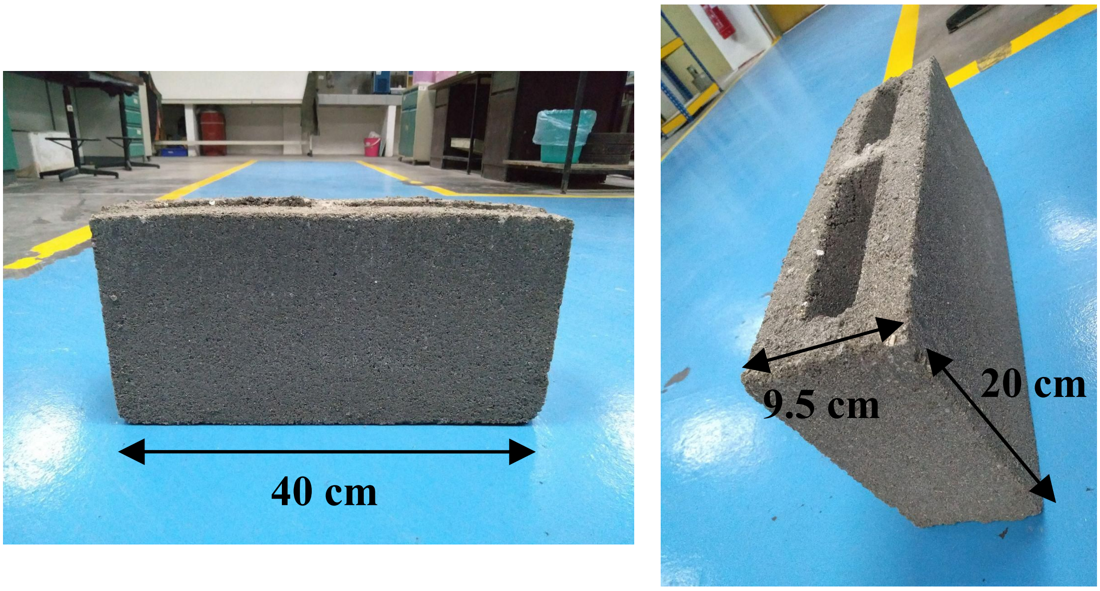

Figure 3.2 Dimension of concrete block

Table 3.2 Number of concrete blocks according to different tests

Type of concrete block	**Compressive strength test**	**Density test, dimensions and tolerances test**	**Initial rate of suction test**	**Water absorption test**
Ordinary concrete block	9	3	3	3
Concrete block with Silica Fume	9	3	3	3

3.5.2 Mixing, Casting and Curing

The mixing process begins by mixing the dry ingredients - sand, silica fume (for the designated concrete block only) and cement in the concrete mixer (as shown in Figure 3.3) for 2 minutes until it achieve homogeneous mix. The concrete mix is then added with water and mixed thoroughly once again for another three more minutes. The concrete mix is created aligned with the mix proportions as determined previously and each mix is equivalent for one concrete block. The mixing process is shown through the photo sets in Figure 3.4.

Figure 3.3 Concrete mixer

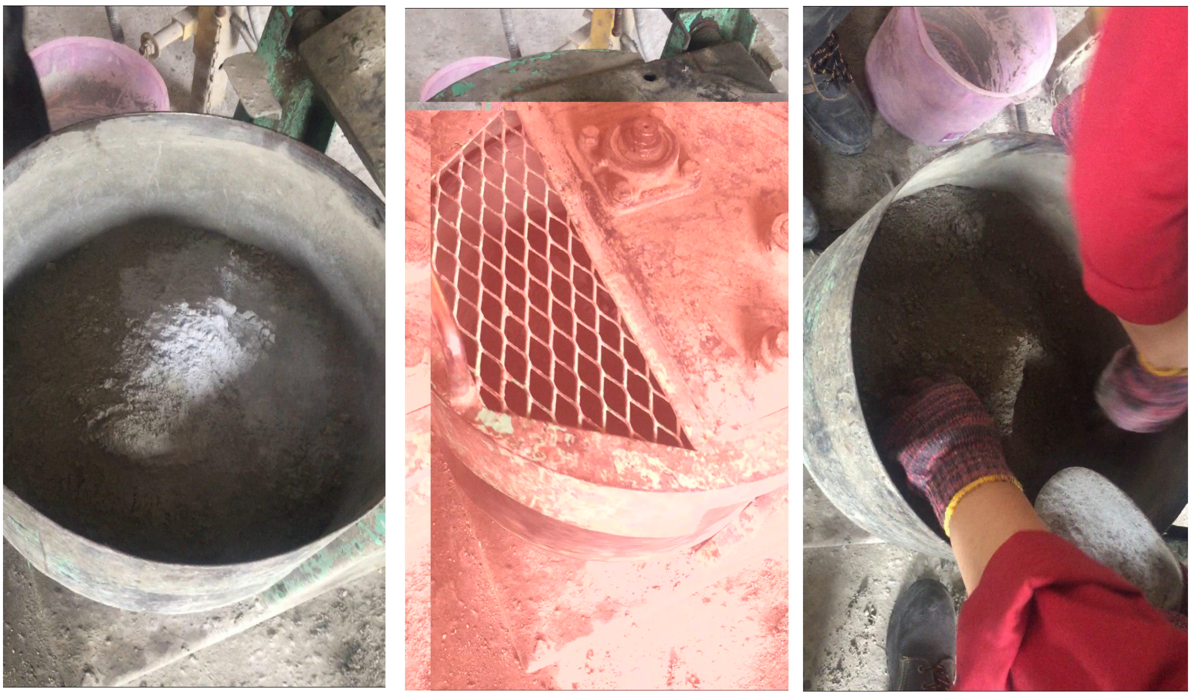

Figure 3.4 Mixing process