A STUDY OF SULPHATE ATTACK RESISTANT ON FIRED CLAY MASONRY UNITS

By

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ABSTRAK

Disertasi ini melaporkan kajian tentang ketahanan bata tanah liat terhadap serangan sulfat. Lima jenis bata tanah liat telah dipilih untuk dikaji ketahanannya terhadap serangan sulfat. Selain itu, kajian juga dilakukan ke atas ciri-ciri bahan dan ciri-ciri mekanikal bagi bata tanah liat untuk mengetahui faktor-faktor yang mempengaruhi ketahanan bata tanah liat terhadap serangan sulfat. Kajian dijalankan untuk mengetahui jenis bata tanah liat yang mempunyai ketahanan terhadap serangan sulfat. Maklumat ini penting supaya bata tanah liat yang sesuai dapat dipilih untuk digunakan di kawasan yang terdedah kepada serangan sulfat. Maklumat yang diperolehi juga sangat berguna bagi membantu pembuat bata memperbaiki ketahan lasakan bata tanah liat semasa menghasilkan bata tanah liat. Walau bagaimanapun, bahan mentah, iaitu jenis tanah liat yang digunakan tidak dikaji kerana kekurangan maklumat mengenainya. Beberapa ujian makmal telah dijalankan untuk mendapatkan maklumat-maklumat mengenai ciri-ciri bahan dan ciri-ciri mekanik bagi kelima-lima jenis bata tanah liat tersebut. Ketahanan bata tanah liat telah diketahui melalui ujian kitaran garam sulfat dengan mendapatkan berapa kitaran yang dilalui oleh sampel bata tanah liat sebelum ia mengalami kegagalan. Hubungan di antara ciri-ciri batah tanah liat dengan ketahanan bata tanah liat terhadap serangan sulfat diperolehi. Kajian ini telah membantu untuk mendapatkan lebih banyak maklumat dalam proses pemilihan bata tanah liat sesuai yang mempunyai ketahanan terhadap serangan sulfat.

ABSTRACT

This dissertation reports the study of the sulphate attack resistance of fired clay bricks. Five types of fired clay bricks had been selected to investigate their ability on sulphate attack resistance. Besides that, study of material property and mechanical property of fired clay bricks had been conducted to determine its influence on the sulphate attack resistance of fired clay bricks. This study needs to define which type of fired clay bricks has sulphate attack resistance. Besides that, this study also stresses on the important of choosing the suitable sulphate attack fired clay bricks to construct buildings at area exposed to sulphate attack. This information is important in helping designer to improve the durability of fired clay bricks when producing sulphate attack resistance fired clay bricks. However, raw materials of fired clay bricks are not defined in this study due to the lack of information about it. A series of laboratory test had been carried out to investigate the material properties and mechanical properties of five types of fired clay bricks. Sulphate attack resistance of fired clay bricks had been observed from cycle test by measuring the number of cycles which causes the brick samples to fail. Relationship between properties of fired clay bricks and its resistance to the sulphate attack was defined. This study will provide more information in choosing the suitable sulphate attack resistance fired clay bricks

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CHAPTER 1

INTRODUCTION

Fired clay bricks are the oldest construction material and until now still remain as one of the important construction materials because of cheaper and easy construction. When choosing the fired clay bricks, durability of material need to be considered to ensure the material can withstand aggressive environment. Therefore, durability of fired clay brick must be known before it can be used. One of the important issues is the resistance of fired clay bricks to sulphate attack.

Sulphate attack is a damaging process to fired clay bricks in sub-tropical and tropical climates. Sources of sulphate may come from soil which consists of high sulphate content or soil at the seaside. Sulphate can only attack to the building in soluble form. Normally, sulphate attack to the mortar is always considered by designer because mortar is exposed to the environment compared to the fired clay bricks which is covered by mortar. However, sulphate attack to the fired clay brick also must be taken care of because bricks form a large part of the building and may damage the structures of building.

An understanding of the relation between material properties and resistance to the sulphate attack and mechanical properties would increase the knowledge of designers, contractors and help manufacturers to improve the durability of fired clay bricks.

1.1 Problem Statement

Resistance of fired clay bricks to sulphate attack become more important as a result of increasing construction activities at the seaside and areas which consist high sulphate content. Sulphate tends to attack fired clay bricks which have low resistance to sulphate attack. As a result of sulphate attack, durability of fired clay bricks will decrease. Sulphate also can harm surface condition of bricks. Structure of building which exposed to sulphate will become vulnerable by not using sulphate resistance fired clay bricks.

Sulphate attack resistance of fired clay bricks still not very consider by bricks manufacturers. This dissertation reports the study of the sulphate attack resistance of fired clay bricks. There are some properties which can influence the sulphate attack resistance of fired clay bricks. For examples, raw materials, material properties and mechanical properties characteristic of fired clay bricks. Only mechanical properties and material properties will be investigated in this dissertation. Influence of raw materials due to sulphate attack resistance of fired clay bricks cannot be investigated due to the lack of raw materials information of fired clay bricks.

Sulphate attack cycling test will be carried out for fired clay bricks. Material properties and mechanical properties of fired clay bricks will be obtained from laboratory test. Then, compare the material properties and mechanical properties of fired clay bricks to the cycling test result and attain the relation between them.

Bricks manufacturers can improve the material properties and mechanical properties of fired clay bricks which will influence the sulphate attack resistance of fired clay bricks. This is to produce fired clay bricks with high sulphate attack resistance.

1.2 Objectives

1. To investigate the water absorption rate for different kind of fired clay bricks.
2. To investigate the sulphate resistance of fired clay bricks.
3. To investigate the material properties and mechanical properties characterisation of fired clay bricks.
4. To develop the relation between compressive strength and resistance to sulphate attack of fired clay bricks.
5. To develop a relation between unit water absorption and resistant to sulphate attack of fired clay bricks.
6. To develop the relation between cycles test with other bricks characteristic.

1.3 Scope of Study

The following works have to be conducted to investigate the sulphate attack resistance of fired clay bricks.

First, a study of the characteristic of different kind of fired clay bricks requires knowing the material properties and mechanical properties of fired clay bricks. Related previous research paper should be referred to know the suitable laboratory test needed to investigate the sulphate attack resistance of fired clay bricks. Then, related standards should be referred to conduct the laboratory test in the right way and acceptable.

After that, laboratory test will begin. Laboratory test are divided into 3 stages. First stage is to investigate the material properties of fired clay bricks. In this stage, size, solid density, porosity, rate of water absorption and water absorption were measured from each fire clay bricks.

The second stage of laboratory test is to investigate the mechanical properties of fire clay bricks. In this stage, compressive strength was measured from each fire clay bricks. In third stage, fired clay brick is exposed to sulphate attack cycle test. Brick samples were dried and soaked in sulphate solution continuously until failure to measure the total cycles which cause bricks sample to failure.

After laboratory tests, compare the material properties and mechanical properties of fired clay bricks to their resistance to the sulphate attack. Get the relation between them and make the conclusion from the results obtained from laboratory test.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to conduct the research of sulphate attack resistance of fired clay bricks, a set of reference books, and previous research papers were referred. First, it is important to know the definition of fired clay bricks and how it was manufactured. It is also important to know what are the sources of sulphate solution and the problems of fired clay bricks caused by sulphate attack. Then properties of fired clay bricks which influence the sulphate attack resistant of fired clay bricks had been learned. These properties are material properties and mechanical properties. Material properties include density, porosity, water absorption and rate of water absorption. Mechanical properties include compressive strength. After the properties of fired clay bricks were known, compare the bricks characteristic and sulphate attack resistance of bricks.

2.2 Definition of Fired-Clay Brick

Fired-clay brick is a brick made from clay soil as main material by mining the clay soil from the ground, preparing, forming into block and firing in high temperature (Richard,1990). Fired-clay bricks is still one of the important construction material because it is cheap and easy to construct depend on the other material like glass. Clay is a natural product formed by the weathering of rock. Clay and shale are the principal materials used to make bricks. Usually it is concentrated in large deposits and these materials are found all over the world.

2.3 Manufacturing of Fired-Clay Bricks

The following are six major steps in the manufacture of fired-clay bricks (Richard, 1990):

1. Mining the raw clay or share from the ground

   Raw material will be removed from ground and stored so that the clay and shale can be blended to yield material with a better composition.

2. Preparing the raw materials for use

   Raw material will be crushed to break up the large pieces into fine material and remove the stones.

3. Forming the raw materials into blocks

   Fine clay soil will be pressed, compacted and wire cut into block size.

4. Pre-drying the bricks for burning

   Bricks are allowed to dry in open air before they were placed in the kiln. This step is needed to remove excess moisture from the bricks to prevent cracking during firing process.

5. Burning the brick in the kiln

Bricks are burnt in the kiln to remove extra moisture from bricks and to harden the bricks in high temperature. According to Richard T. Kreh, Sr. (1990), they are many kind of kiln:

i. Intermittent or periodic kilns

   This type of kiln consists of a single firing chamber and capable of firing only one loading of bricks at a time.

ii. Semi-continuous kilns

   Consist of two or more intermittent kiln which is inter-connected by flues and dampers, to allow heat from the cooling bricks in one kiln to dry and pre-heat the bricks in another kiln.

iii. Continuous kilns

   Firing zone will move through the bricks in the kiln without stopping. Green bricks are loaded from the front of the firing zone and fired bricks removed behind it.

iv. Tunnel kilns

   For this type of kiln, bricks are placed on the trolleys and move through the hottest part of the kiln at a predetermined rate.

6. Storing and shipping

   Drawing bricks the kiln and let it cooled. When bricks are cooled enough, they are banded with metal strips to hold them together for shipment and handling.

2.4 Durability of Fired-Clay Bricks

Durability of fire-clay bricks is defined as the resistance of fired clay bricks to different kind of exposure condition such as frost attack, sulphate attack, efflorescence and lime staining and others. Knowledge on the durability of fired clay bricks is important to understand the performance of fired-clay bricks and to choose the suitable type of fired-clay bricks for construction.

2.5 Sulphate Attack

Sulphate content is an important factor affecting the durability of fired-clay bricks. It is a damaging process to fired clay bricks in sub-tropical and tropical climates. Sulphate may present in soil; ground or sub-soil waters which contain sulphate content, clay bricks contain soluble salt, or soil and ground water at seaside area (Edward, 1994). In their finding, they also point out ashes and clinker, spread over to be used for storing materials, and can transfer sulphate into bricks stacked in contact with them. Anywhere, sulphate can only attack the building in soluble form. Sulphate cannot attack the building in solid state.

Normally, sulphate attack on the mortar joint of clay bricks always considered by designer. This is because concrete surface is exposed directly to the environment compared to the fired clay bricks. However, sulphate attack on the fired clay brick must also to be taken care of because bricks form a large part of the building and may damage the structures of building due to sulphate attack.

2.6 Problems Cause by Sulphate Attack

1. Expansion of fired-clay bricks

   Sulphate solution can absorb into fired-clay bricks and cause the expansion of bricks. Cracking can be found from expanded bricks which will decrease the strength of bricks. According to BS 3921: 1985, sulphate content under 1% have give rise to serious sulphate expansion. Sulphate also gives problem to the mortar joint of bricks and cause expansion of mortar after formation of tricalcium alumina.

2. Formation of stains

   Stain can be seen on the fired-clay bricks surface as a result of sulphate attack which is easily found on light coloured fired-clay bricks (Edward, 1994). This stain came from iron sulphide. Stain is difficult to remove from bricks surface and cause awful surface appearance of fired-clay bricks.

3. Efflorencence

   Salt sulphate solution will dissolve into the bricks (Edward, 1994). As the water evaporates and the bricks wall dries out, the solution become more concentrated until salts begin to deposit. This may occur out of sight within the pore of the bricks or on the surface which call efflorescence.

2.7 Properties of Fired-Clay Bricks Due To Sulphate Attack Resistance

1. Water absorption

   Water absorption of fired clay bricks is defined as quality of water which can be absorbed by fired-clay bricks. They are two types of water absorption which is cold water absorption and boiled water absorption. Water absorption rate of fired-clay bricks influence the durability of fired-clay bricks (Leon Burgess-Dean, 2002). Resistance to sulphate attack on fired-clay bricks will decrease as a result of increasing water absorption rate. Suction of sulphate soluble by fired-clay bricks will increase if the fired-clay bricks have high water absorption rate. These phenomenons will increase the content of sulphate soluble in fired-clay bricks and create problem for the fired clay bricks. The rate of water absorption of fired-clay bricks depends on porosity, raw material used to produce bricks and time of bricks immerse in water (D N Philips et. al., 2002). Table 1.1 as below shows the classification of bricks by water absorption.

Table 2.1: Classification of bricks by water absorption (BS3921:1985)

Class	Water absorption (% by mass)
Engineering A Engineering B	≤ 4.5 ≤ 7.0
Damp-proof course 1 Damp-proof course 2	≤4.5 ≤7.0
All others	No limits

2. Soluble salt content in fired-clay bricks itself

   According to BS 3921:1985, it is very important to know the soluble salt content in fired-clay bricks. High soluble salt contain sulphate ion which will decrease the sulphate attack resistance of fired-clay bricks. High sulphate soluble content inside fired-clay bricks can also cause expansion of fired clay bricks. Normally, soluble sulphate content in fired-clay bricks is negligible and has very little influence on the fired-clay bricks. BS3921:1985 also mentioned that mass of soluble ions in fired-clay bricks shall not exceed the following.

   - Calcium 0.300 % of the mass of fired clay bricks
   - Magnesium 0.030 % of the mass of fired clay bricks
   - Potassium 0.030% of the mass of fired clay bricks
   - Sodium 0.030% of the mass of fired clay bricks
   - Sulphate 0.500% of the mass of fired clay bricks

3. Compressive strength

   Compressive strength is one of the mechanical properties of fired-clay bricks which influence the durability of bricks. Fired-clay bricks with high compressive strength have high resistance to the sulphate attack (D N Philips et. al., 2002). High compressive fired-clay bricks have strong bonding between clay particles. As a result, expansion of fired-clay bricks also becomes very difficult. Compressive strength of fired-clay bricks also depends on porosity of fired-clay bricks (Leon Burgess-Dean, 2002). Less porosity means that high compressive strength in the fired-clay bricks. Table 1.2 attached from BS3921:1985 shows the classification of bricks by compressive strength.

Table 2.2: Classification of bricks by compressive strength (BS3921:1985)

Class	Compressive strength (N/mm^2)
Engineering A Engineering B	≥ 70 ≥ 50
Damp-proof course 1 Damp-proof course 2	≥ 5 ≥ 5
All others	≥ 5

4. Porosity

High porosity in the fired-clay bricks not only decrease the compressive strength of fired-bricks but also decrease the sulphate resistance of fired-clay bricks (D N Philips et. al., 2002). High porosity increases the water absorption rate. As a result, sulphate solution is easy to absorb into the fired-clay bricks which have high porosity. Sulphate solutions will storage in fired-clay bricks and cause expansion of fired-clay bricks.

5. Firing temperature

Firing temperature during manufacturing of fired-clay bricks influence the sulphate attack resistance of fired-clay bricks (D N Philips et. al., 2002). Same type of bricks with different firing temperature was test using cycle test to check the sulphate attack resistance of fired-clay bricks. The result shows that high firing temperature will increase the sulphate attack resistance of fired-clay bricks. High firing temperature during bricks manufacturing process will increase the compressive strength of fired-clay bricks.

2.8 Measurement of Sulphate Attack Resistance of Fired Clay Bricks

Salt attack cycle test is the best method to determine the sulphate attack resistant of fired clay bricks (Leon Burgess-Dean, 2002). Leon Burgess-Dean, (2002) had used cycle test to determine the different of resistance to sulphate attack for different kind of fired-clay bricks. But D N Philips & s Zsembery (2002) had used cycle test to determine the difference of resistance to sulphate attack for same type of fired-clay bricks with different firing temperature during manufacturing. Anyway, methods for cycle test still the same, which is referring to the AS/NZS 4456.10.

According to AS/NZS 4456.10, the following procedure of the cycling test was devised. Firstly, samples with dimension 40x15x15mm will cut down from full size bricks. Then, all samples were dried in the oven at temperature 110˚C for 24 hours. After 24 hours, all the dried samples were move out from oven and allow cooling down at room temperature. After that, dried samples were exposed to cycle of soaking in sulphate solution for 2 hours follow by drying in oven at 110˚C for 24 hours. AS/NZS 4456.10 also mentions that the cycle number at which the deterioration of the samples began was accepted as the first of three consecutive cycles. Cycle test was continued until subsequent cycles.

Concentration of sodium sulphate solution used for cycle test mention in AS/NZS 4456.10 is 14% weight/volume. This is the standard concentration for cycle test. Full size bricks are not preferable for cycle test because longer time needed to obtain the results (D N Philips et. al., 2002). If full size bricks were choosen as samples, more sulphate solution needed to soaking bricks. Moreover, result of cycle test cannot be obtained in short time because sulphate solution needs a very long time to make the full size bricks failed compared to smaller size samples. Cycle test impose a more severe exposure condition on the fired clay body than it is ever likely to encounter in most buildings (D N Philips et. al., 2002). This cycle test procedure may be used as an accelerated test to indicate the resistance of fired clay bricks to salt attack under very severe artificially-created conditions (D N Philips et. al., 2002).

AS/NZS 4456.10 mentioned that a sample is considered failed if test sample has a total mass particle loss of more than 0.4grams. Cycle test samples may conveniently be grouped into three categories below (D N Philips et. al., 2002):

1. Those that did not fail during the test.
2. Those that failed rapidly after a small number of cycles.
3. Those that failed after the cut-off mark of category 2.

Leon Burgess-Dean, (2002) and D N Philips et. al. (2002) conclude that by knowing the number of cycles survived by the specimens, specimens can be categorized into three groups as shown below:

1. High durability

   Those samples that did not fail after 30 cycles.

2. Intermediate

   Those samples that fail between 12 and 30 cycles.

3. Low durability

   Those samples that failed in less than 12 cycles.

As a conclusion, cycle test is able to determine the sulphate attack resistance of fired-clay bricks. This test is easy to conduct, shorter time to wait for the results and results obtained from the test are also related to the real exposure condition of fired-clay bricks to the sulphate. Some modification can be done for this test to know the limits of concentration of sulphate solution which are harmful to the different kind of fired-clay bricks (D N Philips et. al., 2002). This can be done by soaking fired-clay bricks samples into different concentration of sulphate solution.

CHAPTER 3

METHODOLOGY

3.1 Introduction

A series of test had been conducted to investigate the sulphate attack resistance of fired clay bricks. Standard test method for this entire test had been referred to the British Standard, BS3291:1985, and Australian Standard, AS/NZS 4456.10.

Laboratory test had been conducted in three stages. First stage is to define the material properties of fired clay bricks. These tests includes dimension measurement, determination of cold and boiled water absorption, determination of initial rate of suction and determination of porosity of fired clay bricks. Second stage is to define the mechanical properties of fired clay bricks. In this stage, compressive strength of fired clay bricks will be defined. The test method had been referred to the British standard, BS 3291:1985.

Third stage of test is to investigate the sulphate resistance of fired clay bricks. Sulphate attack cycle test is choose. The test method for sulphate attack cycle test had been referred to the Australian Standard, AS/NZS 4456.10.

3.2 Method of Sampling

This method of sampling is referred to the Malaysian Standard, MS 76:1972. According to MS 76:1972, there are two type of sampling which are random sampling and representative sampling. In random sampling, the sample is taken in such a way that every unit in the bulk has an equal chance of being selected as the sample. The appropriate number of bricks shall be selected without any consideration of condition and quality of selected bricks. Representative sampling is use when random sampling is impracticable or not convenient, for example, sampling from a stack and sampling from a consignment formed of banded. In representative sampling, the bulk is divided into convenient sections and the samples are taken so that for each section of the bulk there is a corresponding portion of the sample. The units in each of these portions must be taken in a random manner.

Bricks were delivered to the laboratory in consignment form of banded. As a result, representative sampling was carried out. Bricks on top layer of every pack are removed and samples at the side and bottom of pack are avoided. Equal number of samples was picked from each layer and samples shall pick randomly from each layer without any consideration being given to the condition and quality of the selected bricks.

3.3 Measurement of Dimensions

Dimensions of bricks are needed to get for calculation of bed face area and volume of each type of bricks. Value of bed face area is needed for calculation of compressive strength of bricks and value of volume needed for calculation of density of bricks.

The method of dimensions measurement is referred to British Standard, BS 3921:1985. To measure the dimension of bricks, 24 bricks for each type of fired clay bricks are picked by sampling. The surface of bricks is cleaned using a brush. 24 bricks placed in contact in a straight line upon a level surface. To measure the length of bricks, arrangement of bricks is shown in Figure F.6. For width measurement, arrangement of bricks is shown in Figure F.7, and for depth measurement, arrangement of bricks is shown in Figure F.8. The dimensions of 24 bricks are measured by using a steel tape.

If for any reason, it is found impracticable to measure 24 bricks in one row, the samples may be divided into two rows of 12, of three rows of 8. Dimension of one bricks can be calculated by using the equation (3.1), (3.2) and (3.3).

$$\text{Length of 1 bricks} = \frac{\text{Length of 24 bricks}}{24} \tag{3.1}$$

$$\text{Width of 1 bricks} = \frac{\text{Width of 24 bricks}}{24} \tag{3.2}$$

$$\text{Depth of 1 bricks} = \frac{\text{Depth of 24 bricks}}{24} \tag{3.3}$$

3.4 Determination of Cold Water Absorption of Fired Clay Bricks

Method of cold water absorption measurement is referred to the British Standard, BS 3921:1985. Determination of cold water absorption is use as works control tests. Besides that, value of cold water absorption can be used to get the saturated coefficient and porosity of different kind of fired clay bricks.

Ten bricks for each type of fired clay bricks were picked by sampling. The bricks were dried in ventilated drying oven at temperature 110˚C for at least 48 hours until constant weight of bricks achieved. The 48 hours should be reckoned from the time the specimens reach 110˚C. Prepare enough spaces between bricks when storing bricks into the oven. After 48 hours, all the bricks were extracted from oven and let it cooled down at room temperature for 4 hours in a ventilated room or 2 hours if fan are used. The bricks were cooled down to approximately room temperature.

After bricks were cooled down, the oven dried weights of all the samples were obtained by using a weightier. Then, bricks were immersed in the water for 24 hours. Bricks should immerse in tank with a grid to ensure free circulation of water between bricks and the bottom of tank. After 24 hours immersed in cold water, the specimens were removed from the water. The surface water was wiped off with a damp cloth and the weights of bricks were obtained. This should be done within 2 minutes after remove samples from the water. The cold water absorption of bricks was calculated. Calculation can be done by using Equation 3.4.

$$\text{Cold Water Absorption} = 100\,\frac{(\text{Wet Mass} - \text{Dry Mass})}{\text{Dry Mass}} \qquad (3.4)$$

3.5 Determination of Boiled Water Absorption of Fired Clay Bricks

Boiled water absorption is important to know the ability of water that penetrates into various kinds of fired clay bricks. Value of boiled water absorption can be use to get the saturated coefficient and porosity of various kinds of fired clay bricks.

The test method of boiled water absorption of fired clay bricks is referred to the British Standard, BS3921:1985. Bricks used to determine the cold water absorption were reused to determine the boiled water absorption. The bricks were oven dried in ventilated drying oven at temperature 110˚C for at least 48 hours until the bricks achieved constant weight. The 48 hours should be reckoned from the time the specimens reach 110˚C. Enough spaces were prepared between bricks when storage bricks into the oven. After 48 hours, all the bricks were move out from oven and let it cooled down at room temperature for 4 hours in a ventilated room or 2 hours if fan are used. The bricks were cooled down to approximately room temperature.

After bricks were cooled down, the oven dried weight of all the samples were obtained by using a weightier. Then, the bricks were placed into the boiled tank. Make sure the tank provided with a grid to ensure free circulation of water between bricks and the bottom of tank. The water shall be heated to boiling for 1 hour, and then boiled continuously for 5 hours. After that, allowed to cool down to room temperature for no less than 16 hours or more than 19 hours. The specimens were removed from the boiled tank. The surface water was wiped off with a damp cloth and the weights of bricks were obtained weighing. Weighting of any one of specimen should be done within 2 minutes after removed from the water. The boiled water absorption of bricks were calculate. Calculation can be done by using Equation 3.5.

$$\text{Boiled Water Absorption} = 100\,\frac{(\text{Wet Mass} - \text{Dry Mass})}{\text{Dry Mass}} \qquad (3.5)$$

3.6 Determination of Porosity and Saturated Coefficient of Fired Clay Bricks

Porosity and saturated coefficient of fired clay bricks can be calculated by using the value of cold water absorption and boiled water absorption. Value of porosity and saturated coefficient can get from Equation 3.6 and 3.7.

$$\text{Porosity} = \frac{B - C}{B - A} \times 100 \qquad (3.6)$$

$$\text{Saturated coefficient} = \frac{A}{B} \qquad (3.7)$$

where:

A = Mass of bricks after immersed in water for 24 hours
B = Mass of bricks after boiled in water
C = Oven dry mass of bricks

3.7 Determination of Initial Rate of Suction

Method to measure initial rate of suction is referring to the British Standard, BS3921:1985. Bricks use to determine water absorption of fired clay bricks were reuse to determine the initial rate of suction. Before obtaining the initial rate of suction test, bricks must dry in ventilated drying oven for at least 48 hours. Place the dish on a level table. 2 pieces of angle section metal with size 75mm are place in the bottom of the dish. Then, fill the dish with water until angle section metals are covered to the depth about 3mm.

After drying in oven for 48 hours, move out all the bricks from oven and let them to cool down at room temperature. Then, weight the bricks and record the dry mass of the bricks. After weighting, place the brick bed face downwards on angle section metal and let it immerse for 60 seconds. Ensure that the depth of immersion of the face of the bricks is maintained at 3 ± 1 mm.

After 60 seconds, remove the bricks from dish. Wipe off the surface water with a damp cloth. Then, weight the brick again to get the mass of wet brick. Repeat the procedure to get the initial rate of suction for other bricks. Initial rate of suction can be calculated using Equation 3.8.

$$\text{Initial rate of suction} = \frac{1000\ (\text{Mass of the wet brick} - \text{Mass of the dry brick})}{\text{Area of the immersed face of the brick}} \quad (3.8)$$

Unit of initial rate of suction is kg/mm^2.minutes.

3.8 Determination of Density and Compressive Strength of Fired Clay Bricks

Method used to measure the compressive strength is referring to the Malaysian Standard, MS 76:1972. Machine used to obtain the maximum load on brick is strength test machine. Ten bricks for each type of fired clay bricks were picked by sampling. Immerse bricks in the water for at least 24 hours before strength test. For hollow bricks, immerse the bricks in water for 24 hours. Then fill the hollow in the bricks with a mortar. Mortar contains 1 : 1.5 mix of Portland cement and water / cement ratio of no greater than 0.35. Prepare 6 cubes 75mm from mortar. Immerse the hollow bricks filled with mortar and mortar cubes in water after 1 day. Hollow bricks can be tested if the strength of mortar cubes achieved compressive strength of no less than 28 N/mm^2 and no more than 42N/mm^2. Single cube may be used to indicate the growth of mortar strength, but the final test shall be made with three cubes. The average strength of the three cubes will be taken as the strength of the mortar.

Remove bricks from water after immersed in water for 24 hours. Wipe off the surface water with a damp cloth and weigh to get the weight of bricks. Complete weighting of any one of specimen within 2 minutes after remove from the water. Wipe clean the bearing surface of all the platens and remove any loosen grit or other material from the surface of the specimen. Place the bricks between plywood sheets. The plywood used is 4mm thick three-ply. Make sure to use a fresh pair of plywood sheet for each test. The axis of the specimen shall be carefully aligned with the centre of the ball-seated platen.

After that, apply load at a convenient rate without exceeding 35.0 N/mm^2 per minutes up to half of the maximum load. Then, apply the load at the rate of 15.0 N/mm^2 per minutes and maintain this rate until failure occurs. Record the maximum load (in N). Repeat same procedure to determine the maximum load for other bricks. Compressive strength of bricks can be calculated by using Equation 3.9.

$$\text{Compressive strength} = \frac{\text{Maximum Load}}{\text{Base Face Area}} \tag{3.9}$$

3.9 Sulphate Attack Cycling Test

Sulphate attack cycle test is use to investigate the sulphate resistance of fired clay bricks. Sulphate attack cycle test method is referring to the Australian Standard, AS/NZS 4456.10. Samples with size 40mmx15mmx15mm were cut from full size bricks. Masonry saw is used to cut the bricks. Prepare 5 pieces of samples from 1 brick. Each type of bricks needs 5 bricks to prepare the samples. Prepare the specimens by drying them in the ventilated drying oven at temperature 110˚C for 24 hours. After 24 hours, move out all the specimens from the oven and let the specimens cool down in room temperature.

Prepare sulphate solution at 10%, 15%, 20%, 25% and 30% weight/volume concentration. Weight of sodium sulphate needed to mix with 1000ml water to achieve different concentration is shown in Table 3.6.1.

Table 3.9.1: Weight of Sodium Sulphate Needed To Mix With 1000ml Water for Different Concentration

Concentration of Sodium Sulphate Soluble	Sodium Sulphate Needed Per 1000ml Water (g)
10%	100
15%	150
20%	200
25%	250
30%	300