DEVELOPMENT OF LOW THERMAL MASS CEMENT BLOCK USING PEAT SOIL AND EFFECTIVE MICROORGANISM

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by

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Approved by,

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(Dr. Nur Zulaikha Binti Yusof)

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SERI ISKANDAR, PERAK
September 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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IRHAM HAMEEDA BINTI MOHAMAD IDRIS

ABSTRACT

Peat soil and effective microorganism (EM) based cement-sand block is relatively new in the production of masonry unit, therefore it is important to gather more results in simulating the real conditions on a small scale before it is being introduced to the construction industry. EM is added as it has the potential to reduce the thermal mass of the block through its by-product while peat soil is added as it is expected to undergo degradation by time hence giving a porous structure to the block and make it 'breathable'. In total, seven mixtures of cement-sand block targeted at a 28-days compressive strength of 7 MPa are designed. One control sample is made with a water/cement ratio (w/c) of 0.5, three mixes using 3%, 6% and 10% peat soil replacing sand and three mixes using 10%, 20% and 30% EM replacing water. The block samples are tested for their compressive strength, water absorption and thermal mass conductivity. Blocks with 6% of peat soil and blocks with 30% of EM are the most optimum blocks to be used in the construction of masonry as they successfully reduced the thermal conductivity of the blocks with the value of 1.275 W/mK and 1.792 W/mK respectively when being compared to the thermal conductivity of the control sample which is 2.400 W/mK. Besides, they are also able to achieve the desired compressive strength and water absorption rate. The compressive strength of the samples with 6% of peat soil is 16.48 MPa at 28-days while 30.39 MPa for samples with 30% of EM. Their strengths are higher than the design strength of 7 MPa. On the other hand, the water absorption rate of samples with 6% of peat soil is 7.6% while 6.1% for samples with 30% EM and both are okay since their rate of water absorption is lower than 20%. In conclusion, the addition of peat soil and EM in the cement-sand mix show promising performance as a low cost material to produce low thermal mass cement-sand block.

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I would also like to convey my appreciation to those who has been helping me a lot in the laboratory especially the technologists, Mr. Johan Ariff Mohamed and Mr. Mohamad Ruzaimi Mohammad Pouat. No exception of appreciation for postgraduate students and course mates who has always been willing to share their knowledge as well as being considerate in using the laboratory equipment. Not to forget, all lecturers in Civil and Environmental Engineering Department, especially the course coordinator, Dr. Ng Cheng Yee who always tried her best to make sure the students are being occupied with sufficient materials in completing the course.

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CHAPTER 1

INTRODUCTION

1.1 Background

On a timeline, concrete has been used for over thousands of years. In the early year of concrete invention, it is made by mixing the crude cement which is made from the crushed and burned gypsum or limestone with sand and water (Scrivener and Kirkpatrick, 2008). Concrete block is mainly used as a building material in the construction of walls and sometimes being called as a concrete masonry unit (Hornbostel, 1991). It is a precast concrete product which is usually formed and hardened before they are brought to the job site. In the construction industry, concrete blocks are stacked one at a time and held together with fresh concrete mortar to form the wall. Concrete that is commonly used to make concrete block is a mixture of Portland cement, water, fine and course aggregate such as sand and gravel respectively.

Koski (1992) stated that a typical concrete block weighs 17.2 kg to 19.5 kg. Generally, the concrete mixture used for blocks has a higher percentage of sand and a lower percentage of gravel and water than the concrete mixtures used for general construction purposes. As the percentage of sand is higher, the block is commonly called as cement-sand block. Nowadays, cement-sand block is being used for many kind of purposes especially in the building construction. Thousands of studies are conducted in order to develop a design mix that will produce the best cement-sand block to be used for each type of building walls. One of the thousands of studies regarding this material is the production of low thermal mass cement-sand block. It is an innovation which can improve a building's thermal performance characteristics with the structural and mechanical performance of conventional cement-sand block.

1.2 Problem Statement

Cement-sand block has a high thermal mass where a lot of heat energy is required to change the temperature. Thermal mass is the property that allows a material to absorb, store and later release a significant amount of heat. The block will absorb heat during the day and releasing the heat as temperature falls at night. This might be an advantage for four seasons countries where they need to heat in their house but not for countries in the tropical region especially during the Elnino or drought session.

In contradict, wooden wall that has a low thermal mass can absorb heat easily but they will store less heat and release the heat faster. Therefore, introducing the low thermal mass cement-sand block is one of the method to cool a structure down once the external temperature exceeds comfort levels and ventilation fails to provide comfort. Other than that, low thermally conductive cement-sand block is an ideal material to facilitate the construction of low energy building, which lead to energy saving since it is an important issue in sustainability.

In tropical rainforest regions like Malaysia, a large percentage of total energy input is used for air cooling systems in buildings in order to cope with this climatic condition. Energy consumption in this country that is experiencing rapid urbanization and population growth has shown significance increase over the last few decades. According to Kubota *et al.* (2011), in a survey conducted in 2009, the air conditioner usage was 6 hours on average and the yearly electricity consumption caused by air conditioning recorded the largest amount which was 1167 kWh/year compared to other household electrical appliances.

1.3 Objectives and Scope of Study

The objectives of this study are:

i. To optimize the concentration of EM and peat soil incorporated in cement-sand block.
ii. To test the performance of modified cement-sand blocks for their compressive strength, water absorption rate and thermal conductivity.

Sample of peat soil for this study is collected from a site in Seri Iskandar, Perak, Malaysia. After the sampling is done, it is sun-dried for about two weeks, then it is grinded and allowed to pass through sieve of several sizes before it could be used. While for the EM, it is bought in the form of molasses from the official partner of EM in Malaysia, EMRO Malaysia Sdn Bhd. In order to get the optimization of the composition of EM and peat soil in the cement-sand block, EM is added in the increment of 10% and to the limit of 30% to substitute the volume of water required while peat soil is added in the increment of 3% and to the limit of 10% to substitute the mass of sand required.

Performance of the modified blocks is tested and compared to the performance of the raw blocks. They are tested for their compressive strength, water absorption and thermal conductivity. All of these tests are required in order to analyze the performance of the modified blocks and to determine whether they are suitable to be used for the construction industry as well as to replace the normal block.

CHAPTER 2

LITERATURE REVIEW

2.1 Concrete in Construction Industry and Its Thermal Mass Property

Kosmatka *et al.* (2003) stated that concrete's versatility, durability, and economy have made it the world's most used construction material. The United States uses about 260 million cubic meters of ready mixed concrete each year. It is used in highways, streets, parking lots, parking garages, bridges, high-rise buildings, dams, homes, floors, sidewalks, driveways, and numerous other applications. Concrete production contributes 5% of annual anthropogenic global CO_2 production. CO_2 is a product of the main reaction that makes cement, which is the concrete's main ingredient. Humans have used concrete from a long time ago and nowadays, many development of new concrete additives could produce a stronger, more workable material whilst reducing the amount of cement required and the resulting CO_2 emissions (Damtoft *et al.*, 2008)

A lot of heat energy is required to change the temperature of high density materials such as concrete, bricks and tiles. They are said to have a high thermal mass compared to the lightweight materials such as timber that has a low thermal mass (Reardon, 2013). An appropriate use of thermal mass throughout a building can make a huge difference to comfort, heating and cooling bills. The correct use of thermal mass can also delay heat flow through the building envelope by as much as 10 to 12 hours and produce a warmer house at night in winter and a cooler house during the day in summer (Wilson, 1998). However, for a country that is located in tropical climate region, high thermal mass can cause thermal discomfort. Thermal mass performance is determined by high density, good thermal conductivity and appropriate thermal lag, low reflectivity and high volumetric heat capacity (Baggs and Mortensen, 2006)

2.2 Low Thermal Mass Concrete Vs. High Thermal Mass Concrete

According to the ASHRAE Standard 90.1–Energy Standard for Buildings Except Low-Rise Residential Buildings, the International Energy Conservation Code, and most other energy codes, in some climates, high thermal mass buildings have better thermal performance than low mass buildings, regardless of the level of insulation in the low mass building. The most energy is saved when significant reversals in heat flow occur within a wall during the day. So, mass has the greatest benefit in climates with large daily temperature fluctuations above and below the balance point of the building (55 °F to 65 °F). For these conditions, the mass can be cooled by natural ventilation during the night, and then be allowed to absorb heat during the warmer day.

When outdoor temperatures are at their peak, the inside of the building remains cool, because the heat has not yet penetrated the mass. Although few climates are this ideal, thermal mass in building envelopes will still improve the performance in most climates. Often, the benefits are greater during spring and fall, when conditions most closely approximate the "ideal" climate described above. In heating-dominated climates, thermal mass can be used to effectively collect and store solar gains or to store heat provided by the mechanical system to allow it to operate at off-peak hours.

Any solid, liquid or gas that has mass will have some thermal mass. High density materials such as bricks, concrete, glass and marble have high thermal conductivity ranging from 0.51 W/mK to 1.63 W/mK since they require a lot of heat energy to change their temperature. In contrast, material such as plywood, timber and polyurethane have low thermal conductivity ranging from 0.02 W/mK to 0.16 W/mK (Young, 1992).

2.3 Advantage and Disadvantage of High Thermal Mass Concrete

Reardon (2013) stressed that normal concrete that has high thermal mass gives some disadvantages to its application. Climatic consideration is critical in the effective use of thermal mass for normal concrete. It is possible to design a high thermal mass building for almost any climate but the more extreme climates require very careful design. This is a particularly important issue in tropical climates where temperatures are already close to the upper comfort level.

Use of high mass construction is generally not recommended in hot humid climates due to their limited diurnal range. Passive cooling in this climate is usually more effective in low mass buildings. Thermal comfort during sleeping hours is a primary design consideration in tropical climates. Lightweight construction responds quickly to cooling breezes. High mass can completely negate these benefits by slowly re-releasing heat absorbed during the day.

2.4 Advantage and Disadvantage of Low Thermal Mass Concrete

As energy saving is an important issue in sustainability, the study on whether the presence of EM in concrete block will give a significant effect to its thermal mass or not should be conducted. Since energy consumption of buildings in this country keeps increasing year by year due to the climate condition, urbanization and population growth, the EM incorporated concrete block can be used as building envelop materials to save energy use in buildings as it has a lower thermal mass values and improved thermal insulation properties.

2.5 The Use of Effective Microorganism in Concrete

The concept of effective microorganism (EM) was discovered by Professor Teruo Higa from University of the Ryukyus, Okinawa, Japan. It has a broad application in agriculture, environmental treatment, household usage, medicine healthcare, disaster treatment and construction industry (Higa, 1994). He focused mainly on the agriculture and environmental areas and after that, other researchers started to explore the usage and function of EM for various areas.

According to Kumar *et al.* (2006), concrete technology research has been continuously providing us with the up to date technologies whereby the usage and function of various admixtures have been discovered. By adding additives into the concrete, we are able to enhance the physical, chemical and mechanical properties of it. All of these properties are important in order to prolong the service life of a building. Prolonging the service life of a concrete structure not only save the needs of raw materials for new building but also reduce the construction waste due to the demolishing of the existing building or infrastructure (Zongjin, 2011).

A paper by Ismail *et al.* (2014) presented a review of previous researches related to the influence of incorporating EM into the cement based material. From the review, it is identified that there are two types of EM which is classified as EM product and EM non-product which showed a huge potential as new additives in enhancing the properties of concrete. EM product comes in liquid form and it is widely used in the agriculture sector while EM non-product is not in liquid form and it consists of single colony of bacteria. The introduction of EM in concrete has proved to enhance the mechanical properties of the former but further studies need to be done for better understanding in investigating the mechanism underlies in the microstructure examination of the concrete.

That study is also supported by a study conducted by Sato *et al.* (2003), which their objective was to find the solution for the deterioration problem of concrete structures. EM is added as the admixture and they found that by adding EM into the mix, the workability of fresh concrete improves, initial strength increases and carbonation is suppressed almost perfectly when EM is used in concrete. In conclusion, there are no other materials can improve the quality of concrete in so many aspects like EM.

2.6 Advantage of Effective Microorganism in Concrete

There are several advantages of adding EM into concrete based on previous studies by other researchers. However, no studies conducted to prove that EM could give advantage on the thermal mass of concrete. One of the significant advantages of adding EM into concrete is, it helps concrete to do self-healing when cracks occur. According to the study by Mian *et al.* (2014) which has the objective of developing a bacteria-based self-healing concrete, it is found that there are precipitations of calcite formed at the cracks surface hence, the microbial self-healing agent could be used to achieve the objective.

Sierra-Beltran *et al.*, (n. d.), has conducted a study on the performance of strain-hardening cement-based composites with bacteria. The objective of this study is to measure the bonding and durability of concrete patch repair system. Based on the results, it is reported that the usage of SHCC with bacteria as a concrete patch repair material improved the bonding and durability of the material. Another research is conducted by Van Tittelboom *et al*. (2010) where they investigate the alternative material for synthetic polymers that are being used for concrete repair. Their goal was to produce a repair system which is not harmful to the environment by using biological repair technique. From the study, it is shown that when the bacteria are protected in silica gel, the cracks are filled completely. In conclusion, the use of biological repair technique is desirable because the mineral precipitation induced is pollution free.

There is a research done by Andrew *et al.* (2012), where the objective of the research was to determine the optimum percentage of EM to be added into concrete and to what extend EM is able to enhance the mechanical properties of concrete. From the results, it is found that when 5% of EM is added into the concrete, the compressive, tensile and flexural strength are 143.90%, 25.23% and 19.17% of the design strength respectively. The study concluded that the most economical and optimum percentage of EM to be added into the concrete is 5% as it enhanced the design strength of the concrete. EM in concrete also promotes sustainability to the industry because it is environmental friendly and it will not cause pollution if leakage happens. Other than that, it reduces the risk of Sick House Syndrome.

2.7 Peat Soil and Its Usage

In Malaysia, most of the peatlands have developed along the coast behind the accreting mangrove coastlines, where sulphides in the mangrove mud and water restrict any bacterial activities. This kind of restriction leads to the accumulation of organic matter, the peat. Peat deposits represent 8% of the total land area of Malaysia, which is approximately 2.6 million hectares of land area (Ahmad *et al*., 1991). According to Kallioglou *et al.* (2009), organic soils have an inhomogeneous and anisotropic structure that differs greatly from inorganic soils, resulting in their peculiar engineering properties which usually not favorable for load-bearing. This type of soil generally contains a very high percentage of organic matters and usually water-logged.

Peat soil is generally used to replace the firewood for cooking and heating in Europe, where there are regions that are temperate and boreal. There is diminishing use of peat soil for domestic purposes as peat soil has been used widely in the gas and oil area for cooking and heating fuels during the 20th century. Peat soil is also being used for fueling the electricity as it stimulates the development of large electric power plants. Recently, peat soil has been used to generate electric in small units in the range of 20 to 1000 kW because the carbon and hydrogen contents of the soil are significant to be used as fuel (FAO, 1988).

2.8 Properties of Peat Soil

Inorganic fraction of fresh peat typically accounts for only 2% to 10% of the sample's dry weight. In the other hand, the inorganic fraction of a highly decomposed mucks can increase up to about 60% of the dry weight (Delicato, 1996). In a sample of fresh peat, typically about 80% to 90% of the sample's weight is accounted by water. Organic residues that present in the peat are derived mostly from the vegetative matter, and a lesser extent from microbial sources. The chemical composition of peat is complex and complicated as it contains an enormous number of organic compounds. In addition, the composition peat can vary considerably from bog to bog, and even within the same bog, the chemical composition can change along with the depth of its sampling (Jinming *et al*., 2003).

Delicato (1996) reported that as peat decomposes, there is about 10% decrease in its carbon content, from an initial value of about 50% to 60%, due to the microbial degradation of the vegetative matter. Oxygen percentage is also decrease by about 10% when the humidification of the sample increases from about 43% to 33%. However, there are smaller increase in the percentage of nitrogen and sulphur when the decomposition rate increases while the percentage of hydrogen remains roughly static. Readily degraded materials such as cellulose and hemicellulose are the first to be attacked by the soil microorganisms hence, it can be seen that the percentage level of these materials drops to almost nothing in the highly decomposed peats.

2.9 Peat Soil as Filler in Concrete

Peat soil is usually grayish black to black and its fibrous texture is a result of partially decomposed or undecomposed organic matter. Due to this fibrous structure, combined with the very high void ratio and moisture content, the peat exhibits a sponge-like behavior and is highly compressible (Senanayake, 1986). Based on the previous study by Deboucha and Hashim (2011), peat soil has been added into the brick mix to produce lightweight bricks. The results showed that the compressive strength of stabilized peat bricks that are under 6 MPa and 10 MPa pressure are 5.48 MPa and 7.10 MPa respectively while the water absorption of the bricks are 4.75% and 2.6% respectively. From the study, they found that increase in strength will decrease the water absorption and hardening of bricks along time.

2.10 Other Materials Used in Concrete to Reduce Its Thermal Mass

Previous studies have shown the incorporation of several materials to produce the low thermal mass concrete. Uysal *et al.* (2004) indicated that the usage of pumice aggregate (PA) as replacement of normal aggregate decreased the thermal mass of concrete up to 46%. Another previous research works proved that by using expanded perlite aggregate (EPA) as replacement of PA and silica fume (SF) and fly ash (FA) as replacement of cement in concrete mixes, the thermal mass can be lowered to about 0.15 W/Mk (Demirboga and Gul, 2003). However, limited research has been done on assessing the thermal insulation property of concrete produced with EM incorporation.

CHAPTER 3

METHODOLOGY

3.1 Sampling and Preparation of Peat Soil

Sample of peat soil for this study is collected from a palm oil plantation located in Seri Iskandar, Perak, Malaysia. The soil is sampled through a random sampling. Peat soil that has been sampled is prepared by sun-drying and crushing it prior the sieving. The particle size which give the largest amount is used in this study to replace the river sand in several proportions.

3.2 Preparation of Conceptual Design of Mortar Mix

The conceptual design of mortar mix is prepared to show the proportion of Ordinary Portland Cement (OPC), river sand and water that is being used in the mix. The material proportion in the mix for one number of mould is calculated as per below:

Volume of mould = 50 x 50 x 50

$$= 125\ 000\ \text{mm}^3 = 0.000\ 125\ \text{m}^3$$

From the volume, since cement/sand ratio is 1:4,

$$\text{Volume of cement} = \frac{0.000\ 125\ \times 1}{5}$$

$$= 0.000\ 025\ \text{m}^3$$

$$\text{Volume of sand} = \frac{0.000\ 125\ \times 4}{5}$$

$$= 0.000\ 1\ \text{m}^3$$

Density of cement is 3150 kg/m^3,

Weight of cement = 0.000 025 x 3150

= 0.078 75 kg = 78.75 g

Density of sand is 2600 kg/m^3,

Weight of sand = 0.000 1 x 2600

= 0.26 kg = 260 g

Hence, from the calculation, the mix proportion for one cube of control sample is as per Table 1.

Table 1. Mix proportion for a 50 x 50 x 50 mm mould for control sample

Water/Cement Ratio	**Sand (g)**	**Cement (g)**	**Water (mL)**
0.5	260	78.75	39.38

Other than that, mix design for a series of EM and peat soil incorporated cement-sand block are prepared too. The percentage of peat soil to replace the weight of sand is set at 3%, 6% and 10% and the same goes to EM, its percentage to replace the volume of water is set at 10%, 20% and 30%.

Table 2. Mix proportion for a 50 x 50 x 50 mm mould for PS formulation

% of Peat Soil from Sand	**Water (mL)**	**Cement (g)**	**Sand (g)**	**Peat Soil (g)**
3	39.38	78.75	252.20	7.80
6	39.38	78.75	244.40	15.60
10	39.38	78.75	234.00	21.67

Table 3. Mix proportion for a 50 x 50 x 50 mm mould for EM formulation

% of EM from Water	**Water (mL)**	**EM (mL)**	**Cement (g)**	**Sand (g)**
10	35.44	3.94	78.75	260
20	31.50	7.88	78.75	260
30	27.56	11.81	78.75	260

3.3 Preparation of Mortar Samples

Mortar samples are prepared in order to conduct the testing. For each mix design, certain numbers of sample are prepared to make sure all testing could be conducted.

Table 4. Mortar samples needed for testing

Testing	Standard Test Method	No. of samples needed for each mix design
Compressive Strength	BS EN 1015-11:1999	12
Water Absorption	BS EN 1015-18:1999	3
Thermal Conductivity	BS EN 1934:1998	3

3.4 Curing of Mortar Samples

All of the mortar specimens are demolded after 24 hours of casting and cured in a water tank at a temperature of 27 ± 2 °C until the test ages. According to Andrew *et al.* (2012), the mortar samples should be cured in water with the addition of EM diluted hundred times as advised by the personnel from Effective Microorganisms Research Organization (EMRO), Japan. Distilled water is used in the dilution to ensure that it is chlorine free to prevent EM from encountering death. However, in this study, the curing is done in tap water in order to avoid microbial dissemination and contamination. Furthermore, tap water is more practical to be used for the real application in construction industry.

3.5 Testing of Mortar Samples

3.5.1 Determination of compressive strength

This test is carried out at the mortar ages of 7, 14, 21 and 28 days in accordance with BS EN 1015-11:1999 to know the compressive strength of the sample. The procedure of conducting this test in accordance to the standard is as follow. Firstly, the specimen is removed from the water after a specified curing age and excess water is wiped out from the surface. The bearing surface of the testing machine is ensured to be cleaned before placing the specimen inside it. The specimen is placed in the machine and aligned centrally on the base plate of the machine. The movable portion is rotated gently by hand so that it touches the top surface of the specimen. The load is applied gradually without shock and continuously till the specimen fails. The compressive strength of the specimen is recorded to the nearest 0.05 N/mm^2 and the mean result to the nearest 0.1 N/mm^2.

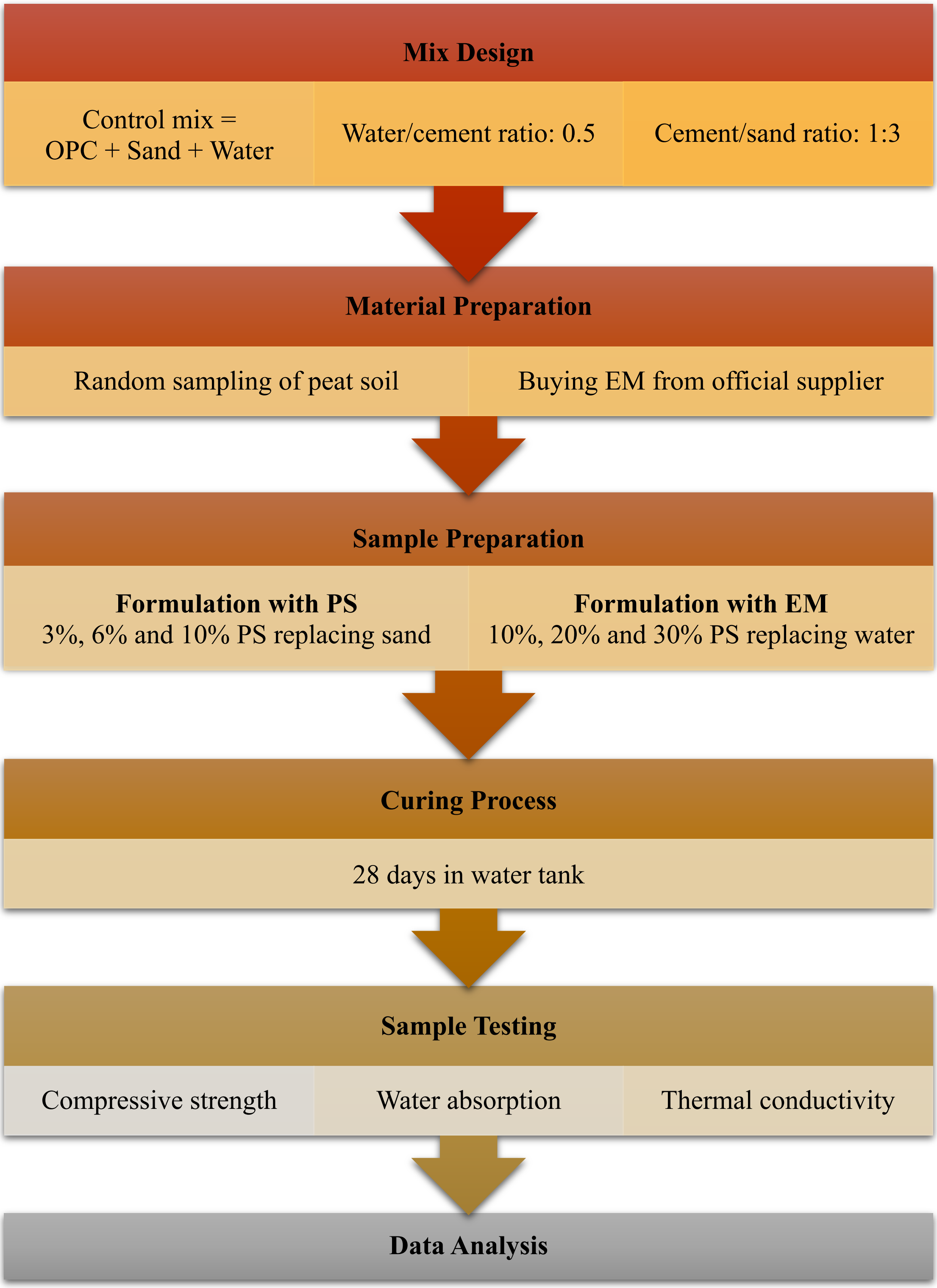
3.5.2 Determination of water absorption

This test is carried out according to BS EN 1015-18:1999 to find the rate of water absorption of the sample after 28 days. The procedure of conducting this test in accordance to the standard is as follow. Firstly, the specimen is weighed in its dry condition. Then, it is immersed in fresh water for 24 hours. After being immersed, the specimen is removed from the water and excess water is wiped out from the surface. The specimen is weighed in its wet condition to get the difference between its weights during dry and wet condition. The amount of difference is the amount of water absorbed by the specimen.

3.5.3 Determination of thermal resistance

This test is carried out according to BS EN 1934:1998. After the curing, the samples will be placed in an oven for 24 h at 105 °C to drive out the free moisture. The procedure of conducting this test in accordance to the standard is as follow. Firstly, the sensor is cleaned to make sure it is not in contact with other matter. Three drops of distilled water are dropped on the sensor. The test can be started once the specimen is placed on the sensor. The test is stopped when 10 readings are obtained.

3.6 Flow Chart



CHAPTER 4

RESULTS AND DISCUSSION

4.1 Compressive Strength

4.1.1 Result of compressive strength test for samples with peat soil

Figure 1 shows the relation of compressive strength versus age of mortar samples containing peat soil in 3%, 6% and 10%. The graph shows, longer curing age of samples increases the strength. However, there are samples having lower compressive strength at 28-days of curing age compared to their strength at 14-days of curing age which are the samples with 6% peat soil and 10% peat soil.

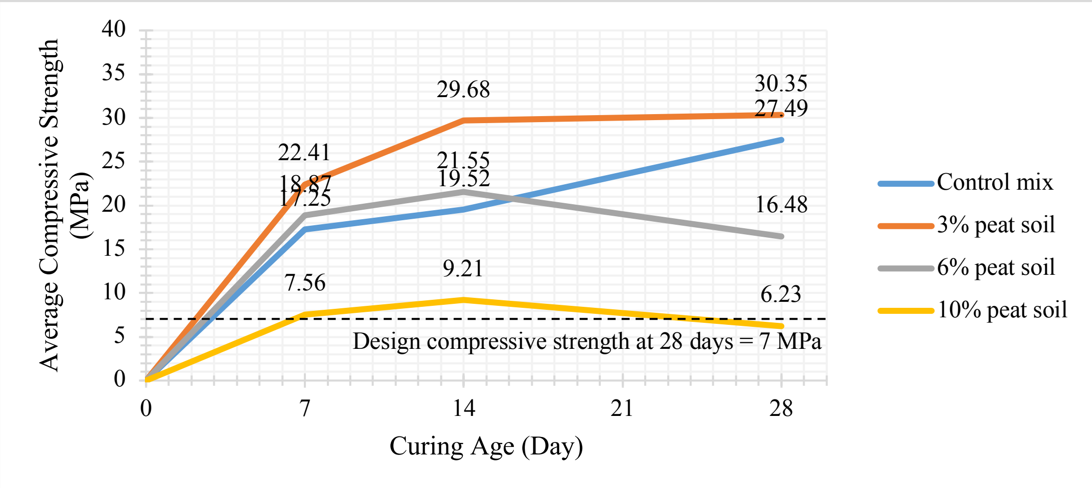


Figure 1. Compressive strength based on curing age for samples with PS

Reduction in the compressive strength at 28-days for samples with 6% peat soil and 10% peat soil is due to the usage of different type of mould during the preparation of the samples. Samples that are prepared by Type 1 mould could performed well while samples that are prepared by Type 2 mould could not perform really well. For Type 2 mould, it could be observed that after it is being unmoulded, the dimensions of some samples are not accurate hence affecting the compressive strength of the samples. From all samples with peat soil addition, sample with 3% peat soil had the highest compressive strength in all curing ages.

At the age of 7-days, 14-days and 28-days, samples with 3% peat soil and 6% peat soil are stronger than the control sample but samples with 6% peat soil at 28-days is weaker than the control sample. Compressive strength for 7-days samples with 3% peat soil is 22.41 MPa and samples with 6% peat soil is 18.87 MPa whereas the control sample is only 17.25 MPa. Compressive strength for 14-days samples with 3% peat soil is 29.68 MPa and samples with 6% peat soil is 21.55 MPa whereas the control sample is only 19.52 MPa. Compressive strength for 28-days samples with 3% peat soil is 30.35 MPa whereas the control sample is only 27.49 MPa. Samples with 3% peat soil and 6% peat soil show a greater strength compared to the control sample. The 7-days compressive strength for 3% peat soil is already able to achieve 320% of the design strength, compared to the control sample which only achieved 146% of the design strength. These results are significant to the mortar production process because it will shorten the mould removal process and eventually improves the production timeline. Besides, it is also crucial to achieve a high early strength if the mortar brick is to be produced in the construction site as it will help shorten the construction period.

However, at 28-days, samples with 6% peat soil is 16.48 MPa which is weaker than the control sample. In the other hand, samples with 10% peat soil is weaker than the control sample at all of the ages. Compressive strength for samples with 10% peat soil is only 7.56 MPa at 7-days, 9.21 MPa at 14-days and 6.23 MPa at 28-days. It can be observed from Figure 1 that compressive strength decreased when the percentage of sand replacement by peat soil increased. Compressive strength depends on the strength of matrix and particle strength of aggregate (Gunasekaran *et al.*, 2012). Peat soil contains particles of organic matter and it is easily compressed. Peat soil is weaker than sand hence, the higher the percentage of peat soil used to replace the sand, the lower the compressive strength of the mortar samples will be. Furthermore, according to L.S. Wong *et al.* (2013), hydration of the cement does not happen due to the presence of acidic organic matter in the peat soil.

4.1.2 Result of compressive strength test for samples with EM

Figure 2 shows the relation of compressive strength versus age of mortar samples containing EM in 10%, 20% and 30%. As the graph shows, higher age of samples increases the strength. However, there are samples having lower compressive strength at 28-days of curing age compared to their strength at 14-days of curing age which are the samples with 10% EM and 20% EM.

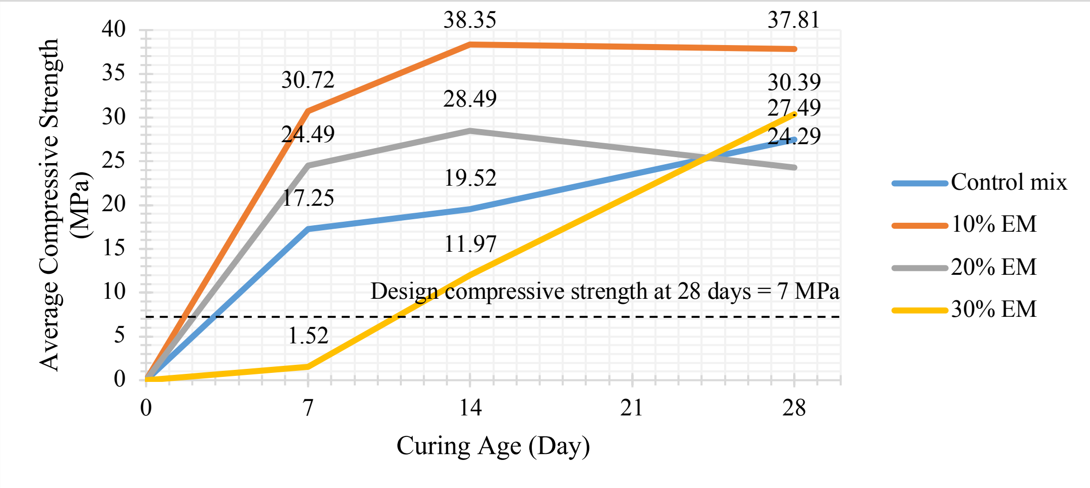


Figure 2. Compressive strength based on curing age for samples with EM

Reduction in the compressive strength at 28-days for samples with 10% and 20% EM is due to the usage of different type of mould during the preparation of the samples. Samples that are prepared by Type 1 mould could performed well while samples that are prepared by Type 2 mould could not perform really well. For Type 2 mould, it could be observed that after it is being unmoulded, the dimensions of some samples are not accurate hence affecting the compressive strength of the samples. From all samples with EM addition, sample with 10% EM had the highest compressive strength in all curing ages.

At the age of 7-days, 14-days and 28-days, samples with 10% EM and 20% EM are stronger than the control sample but samples with 20% EM at 28-days is weaker than the control sample. Compressive strength for 7-days samples with 10% EM is 30.72 MPa and samples with 20% EM is 24.49 MPa whereas the control sample is only 17.25 MPa. Compressive strength for 14-days samples with 10% EM is 38.35

MPa and samples with 20% EM is 28.49 MPa whereas the control sample is only 19.52 MPa. Compressive strength for 28-days samples with 10% EM is 37.81 MPa whereas the control sample is only 27.49 MPa. Samples with 10% EM and 20% EM show a greater strength compared to the control sample. The 7-days compressive strength for 10% EM is already able to achieve 439% of the design strength, compared to the control sample which only achieved 146% of the design strength. These results are significant to the mortar production process because it will shorten the mould removal process. High early strength that is achieved by the mortar brick not only benefits the tight schedule of construction but also reduces the expensive cost of using chemical admixtures into the mix since EM is relatively cheaper than any chemical admixtures.

However, at 28-days, samples with 20% EM is 24.29 MPa which is weaker than the control sample. In the other hand, samples with 30% EM is weaker at 7-days and 14-days ages but stronger at 28-days compared to the control sample. Compressive strength for samples with 30% EM is only 1.52 MPa at 7-days and 11.97 MPa at 14-days but at 28-days, it increases rapidly to 30.39 MPa. Figure 2 also shows that compressive strength of the samples decreased when the percentage of water replacement by EM increased. This finding can be connected to the previous study by Andrew *et al.* (2012) that the increase in the percentage of EM affects the hydration process of the mortar samples hence, caused a lower compressive strength. Compressive strength of samples with 30% EM that is lower than the strength of control sample proves that beyond 20% of EM added, hydration process in the sampled will be affected the most. EM contains lactic acid hence the hydration process could be interrupted due to the characteristic of EM that is acidic while a normal mortar mixture is alkaline. According to Kastiukas *et al.* (2015), a saturation limit may exist after a significant amount of lactic acid produces a hydrate which does not benefits the strength and it no longer enhances the precipitation of hydrates but instead blocks it.

4.2 Water Absorption

4.2.1 Result of water absorption test for samples with peat soil

Figure 3 shows the relation of water absorption rate versus percentage of peat soil replacing the sand in the mortar mix. At the age of 28-days, only samples with 3% peat soil achieved a lower rate than the control sample which is 6.6%. The other samples which are samples with 6% and 10% peat soil obtained 7.6% and 8.1% rate of water absorption respectively which are higher than the rate of the control sample. Water absorption rate for the control sample is 7.0%.

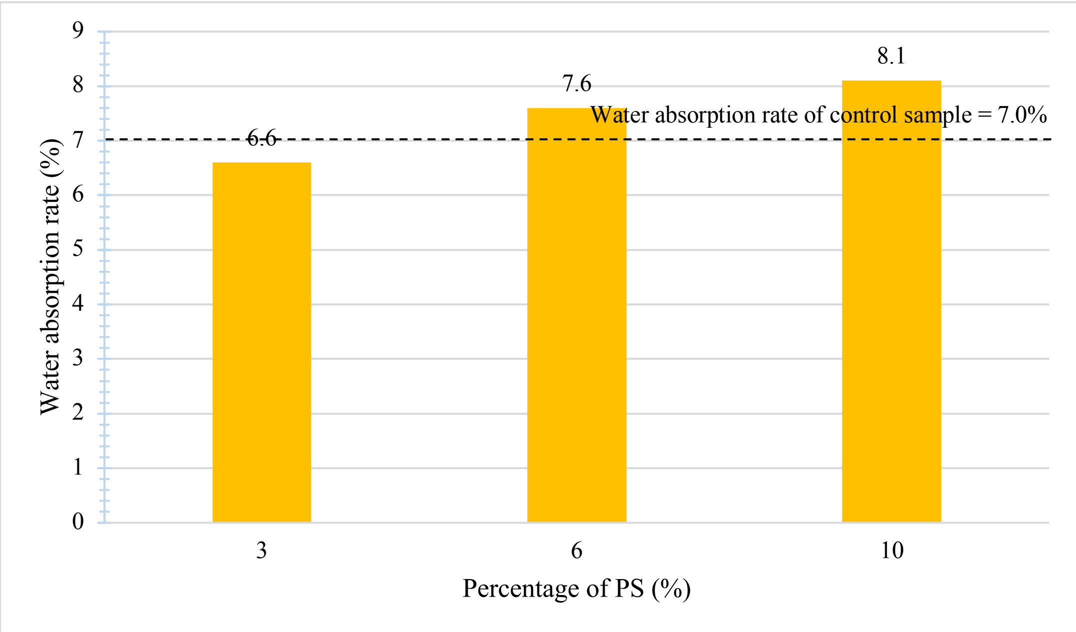


Figure 3. Water absorption rate for samples with PS

The graph shows that the higher the amount of peat soil used in the samples increases their rate of water absorption According to Feustel and Byers (1936), although peat soil contains greater amount of water than sand, it also held water too tightly compared to the sand. Dachnowski-Stokes (1929) and Longley (1930) also stated that peat soil has a high moisture-holding capacity. On the other hand, by referring to the graph in Figure 1, the higher the amount of peat soil used in the samples decreases their compressive strength. These two findings can be connected and they are supported by a previous study conducted by Deboucha and Hashim (2011). In the study, they showed that the correlation between compressive strength and water absorption of samples containing peat soil is negative which means, increase in compressive strength will decrease the water absorption rate of the samples. In connecting the previous study and the current study, higher amount of peat soil used to replace the sand will lower the compressive strength and higher the water absorption rate of the samples.

Through this experiment, all samples are able to achieve rates that are lower than 20% which means all samples are good in quality. This is because, according to IS: 3952 (1988), water absorption of ordinary burnt clay blocks should not be more than 20% of the samples' dry weight. However, it could be observed that when 3% of sand is being replaced by peat soil, it produced samples with the lowest rate of water absorption. They are 5.7% lower than the water absorption rate of the control sample hence they are better to be used for construction.

4.2.2 Result of water absorption test for samples with EM

Figure 4 shows the relation of water absorption rate versus percentage of EM replacing the water in the mortar mix. At the age of 28-days, samples with 20% and 30% EM achieved lower rate than the control sample which is 6.6% and 6.1% respectively. The other sample which is samples with 10% EM obtained 7.4% rate of water absorption which is higher than the rate of the control sample. Water absorption rate for the control sample is 7.0%.

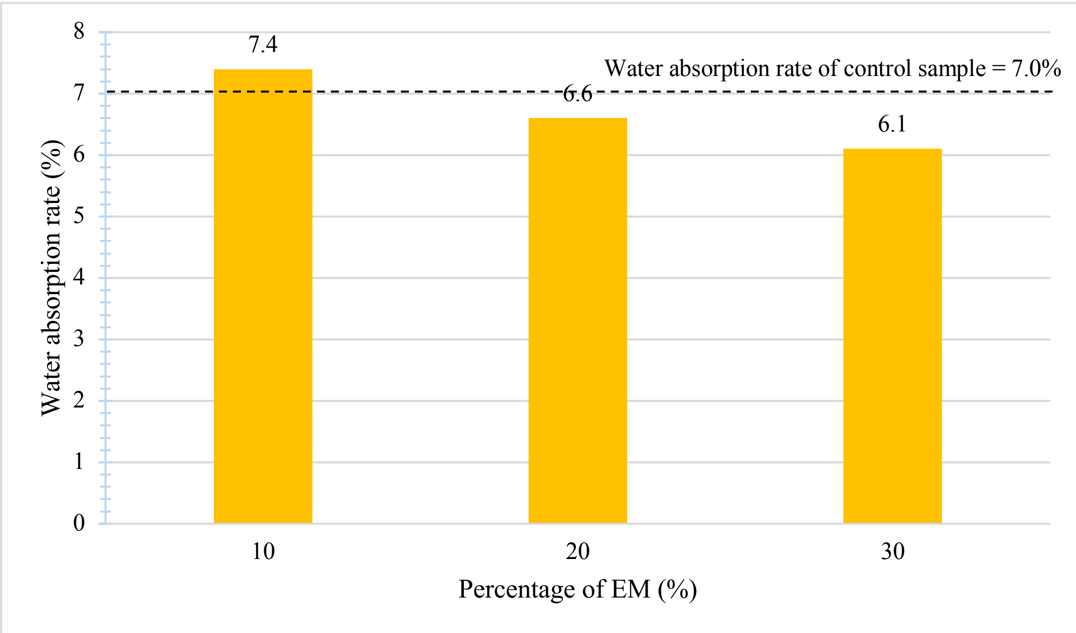


Figure 4. Water absorption rate for samples with EM

The graph shows that the higher the amount of EM used in the samples decreases their rate of water absorption. Through this experiment, all samples are able to achieve rates that are lower than 20% which means all samples are good in quality. This is because, according to IS: 3952 (1988), water absorption of ordinary burnt clay blocks should not be more than 20% of the samples' dry weight. However, it could be observed that when 30% of water is being replaced by EM, it produced samples with the lowest rate of water absorption. They are 12.9% lower than the water absorption rate of the control sample hence they are better to be used for construction.

4.3 Thermal Conductivity

4.3.1 Result of thermal conductivity test for samples with peat soil

Figure 5 shows the relation of thermal conductivity versus percentage of peat soil replacing the sand in the mortar mix. At the age of 28-days, all samples with peat soil achieved lower k-value than the control sample. Thermal conductivity value for samples with 3% peat soil is 2.294 W/Mk, 1.275 W/Mk for samples with 6% peat soil and 1.635 W/mK for samples with 10% peat soil whereas the control sample achieved as high as 2.400 W/mK.

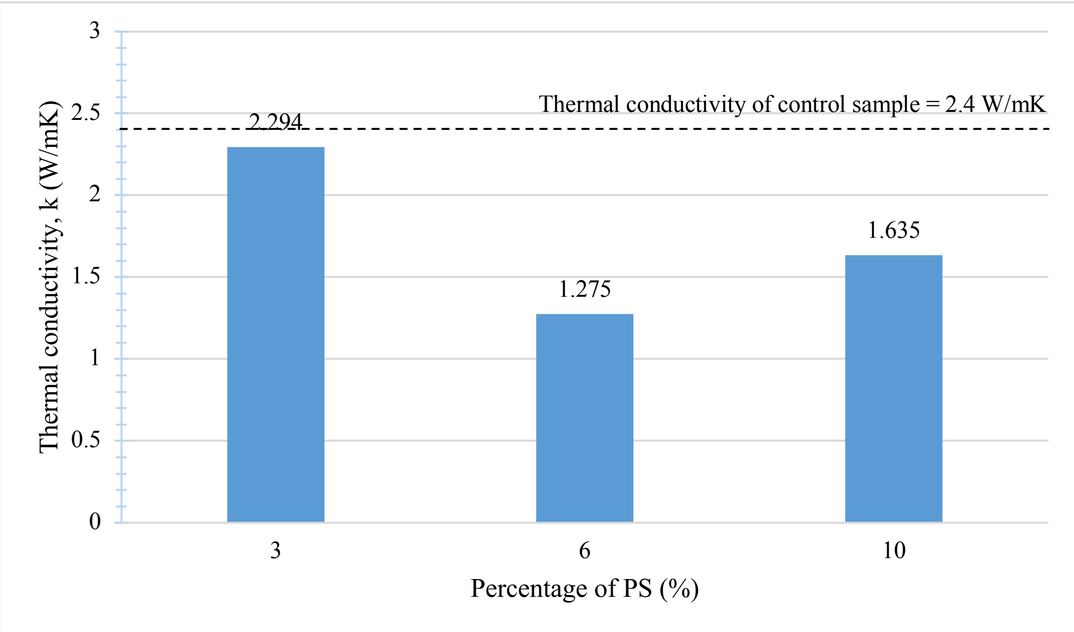


Figure 5. Thermal conductivity result for samples with PS

According to Eggelsmann *et al.* (1993), thermal conductivity of peat soil is heavily dependent on the water content of the soil. The higher the water content is, the more improvement in the thermal conductivity. In addition, Farouki (1981) stated that the thermal conductivity of organic soils such as peat soil is very low. They are ranging from 0.50 W/mK at saturation state to 0.06 W/mK under dry conditions. Through this experiment, it could be observed that when 6% of sand is replaced by peat soil in the mix, it produced samples with the lowest thermal conductivity value and they are 46.9% lower than the thermal conductivity value of the control sample.

4.3.2 Result of thermal conductivity test for samples with EM

Figure 6 shows the relation of thermal conductivity versus percentage of EM replacing the water in the mortar mix. At the age of 28-days, all samples with EM achieved lower k-value than the control sample. Thermal conductivity value for samples with 10% EM is 2.206 W/mK, 2.024 W/mK for samples with 20% EM and 1.792 W/mK for samples with 30% EM whereas the control sample achieved as high as 2.400 W/mK.

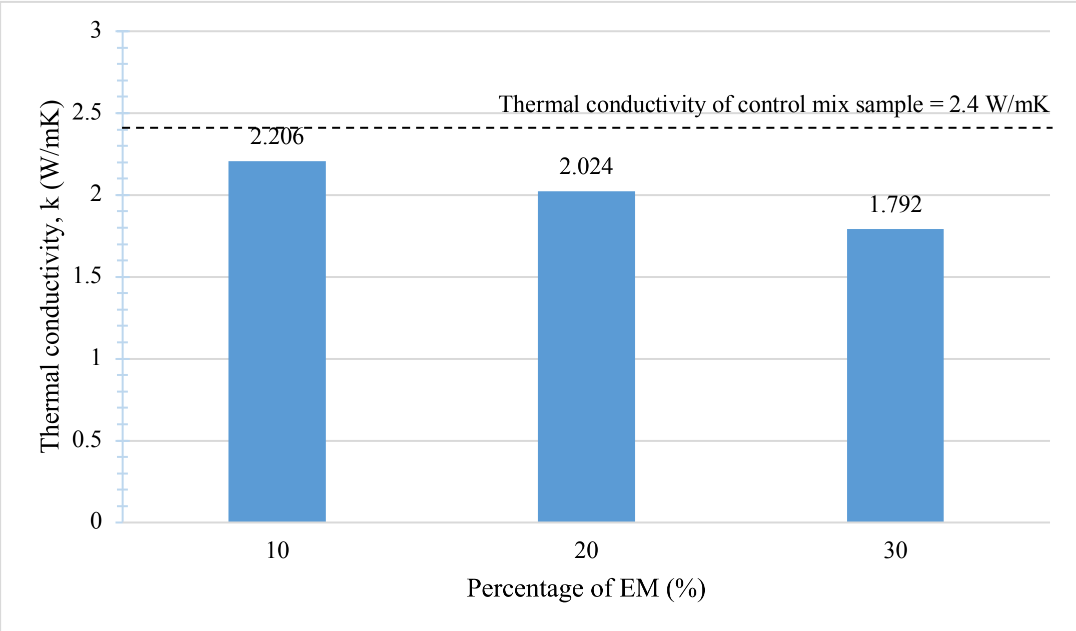


Figure 6. Thermal conductivity result for samples with EM

EM that is being used in this study is in liquid state and it is activated by mixing it with molasses for its medium of growth. Acording to Broadfoot *et al.* (1990), molasses has a thermal conductivity as low as 0.35 W/mK. Comparing the value with the thermal conductivity of water which is ranging from 0.52 W/mK to 0.69 W/mK, it shows that molasses has a lower value of thermal conductivity. Through this experiment, it could be observed that when 30% of water is replaced by EM in the mix, it produced samples with the lowest thermal conductivity value and they are 25.3% lower than the thermal conductivity value of the control sample.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the above results and discussions, several conclusions that can be made are:

i. Most of the samples that consist up to 6% of peat soil replacing the sand and 30% of EM replacing the water able to achieve higher compressive strength than the design strength of 7 MPa at 28-days with the range of 16.48 MPa to 37.81 MPa.
ii. Rate of water absorption for all samples are lower than 20% of the samples' dry weight hence they can be considered as durable. Furthermore, samples with 3% of peat soil replacing the sand, 20% and 30% of EM replacing the water able to obtain lower rate of water absorption compared to the water absorption rate of the control samples which are 7.0%. The water absorption rate for samples that produced lower rate are 6.6%, 6.6% and 6.1% respectively.
iii. Thermal conductivity of samples with 6% of peat soil replacing the sand and 30% of EM replacing the water able to produce samples which are 1.275 W/mK and 1.792 W/mK respectively and they are lower than the thermal conductivity of the control samples which are 2.400 W/mK.

As a conclusion, peat soil and effective microorganism incorporated cement-sand blocks successfully reduced the thermal mass with desired compressive strength and water absorption rate. Blocks with 6% of peat soil and blocks with 30% of EM are the most optimum blocks to be used in the construction of masonry.

5.2 Recommendation

Based on the value of thermal conductivity obtained, a mix consists of 6% of peat soil replacing sand and 30% of EM replacing water could be designed to determine whether such combination could produce a lower value of thermal conductivity or not. However, it should be aware that the usage of 30% of EM in the samples could lead to a very low early compressive strength which is 1.52 MPa based on the compressive strength test. The mechanical performance and durability of samples with such combination should be ensured to stay within the desired range.

Other than that, morphology analyzing could be done through the FESEM-EDX method. The study on microstructure examination is important in understanding the mechanism underlies due to microbial activity in a cement based material. Generally, the FESEM-EDX is essential in visualizing the image and getting the morphological information and mineralogical composition of the raw as well as modified concrete blocks. Through this kind of analysis, we could know study the reasons of every performance shown by the samples.

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