The selection of optimum water-cement ratio for production of low thermal conductivity cement sand brick with Oil Palm Mesocarp Fibre as admixture

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Abstract. The development of housing construction project in Malaysia has rapidly increasing. However, the development of the projects only focusing on the exterior look without giving consideration on the thermal properties of materials used for building envelopes which may influence to external gain and thermal comfort for the occupants inside. As way to encounter the problem, one of the methods is by passive design which through utilized a low thermal conductivity of brick wall in creating good thermal insulation of the building envelopes. This study investigated the characteristics of the cement sand brick (CSB) with incorporated of Oil Palm Mesocarp Fibre (OPMF) as admixture by using different water-cement ratio ranging from 0.45 to 0.65. All bricks were tested for compressive strength, water absorption and thermal conductivity. The result reveals that the higher water-cement ratio increased the compressive strength and water absorption, while decreased in thermal conductivity of bricks. It was found that, by incorporating of 0.65 water-cement ratio enhances the production of low thermal conductivity brick with value of 0.891 W/mºC, compressive strength of 12.4 MPa and water absorption of 1.99% that meets the standard requirement. Foremost, the incorporation of OPMF with water-cement ratio of 0.65 provides alternative solution for energy efficiency and improve the comfort in buildings by improving CSB insulation properties.

1. Introduction
Malaysia had generated in excess of 15,000 tons of solid waste per day in the form of biomass that consists of forest and mill residues, agricultural waste, wood wastes and municipal wastes [1]. The increase in the quantity of agricultural industries in Malaysia supports economic growth positively, but it affects the environment contrarily by generating large amounts of wastes. Internationally, 998 million tons of agricultural waste were produced in a year and in Malaysia, 1.2 million tons of agricultural waste is disposed into landfills annually [2].

In 2015, Malaysia Palm Oil Council (MPOC) reported that approximately 5.1 million hectares of land crosswise over Peninsular Malaysia, Sabah and Sarawak were planted with oil palm, with more than 200 palm oil mills currently operating [3]. The wastes such as Empty Fruit Bunch (EFB), Palm Kernel Shell (PKS), Oil Palm Mesocarp Fibre (OPMF), Palm Oil Mill Effluent (POME), Oil Palm Trunk (OPT), Oil Palm Leaves (OPL) and Oil Palm Fronds (OPF) are produced after the oil palm
fruits harvesting, palm oil processing or during oil palm trees replantation [4]. These wastes are simply disposed of without any economic return [5].

Oil Palm Mesocarp Fibre (OPMF) otherwise known as palm pressed fibre (PPF) is the biomass residue acquired subsequent to pressing the palm fruits for palm oil extraction. Approximately, 11% of OPMF is created from the palm fruits after the oil extraction [6]. Being a lignocellulosic material, OPMF has grabbed the attention of researchers due to its potential utilization for biocomposite production [7-8], whereby the fibre can be used to strengthen polymer materials such as thermoplastics.

Hence, utilization of agricultural wastes in the bricks production seems to be a solution not exclusively to environmental pollution yet additionally to the design of green building [9]. Besides that, the use of wastes as materials to increase thermal insulation, turn into a solution which offers a reduction in resource use, advance reusing of the wastes, less dependent on toxic substances composes in wood or cellulose-based insulators, and reducing energy consumed by altering indoor air temperature conditions [10].

Modern housing buildings became more dependent on artificial means to provide comfortable thermal environment with high energy consumption. The increase in energy consumption by the housing buildings is mainly because of the growing demand for air-conditioning systems to provide thermal comfort for building’s occupants. This high energy consumption is mostly related to poor thermal performance of building envelope [11]. This situation happened due to modern housing buildings are fully exposed to solar radiation, which will increase the ambient temperature inside and affects the occupants comfort.

Natural fibre bricks offer a competitive alternative to conventional building materials since they utilize local resources that can be both costs effective and energy efficient, and closely follow existing masonry construction practices. By adding natural fibres in cement sand bricks has been reported can improve the mechanical properties and flexibility of bricks [12-13]. There are numerous studies have been done on the development of thermal insulation materials from natural fibres used as environmental-friendly and renewable materials such as rice husk, bagasse and corncob [14], maize husk, maize cob, groundnut shell, coconut pith and paddy straw, eggplant stalks, tamarind hulls and cotton fibres [15].

Typically, there are many types of bricks manufactured in the factories all around the world. The most common brick is the traditional fired clay brick and a huge amount of energy is depleted throughout its production [16]. Sand cement brick (CSB) is a kind commonly used in low and medium cost housing development and other commercial constructions in Malaysia. CSB is easy to make and inexpensive to produce [17]. Thus, CSB will be a better way to replace clay brick which significantly less expensive.

Therefore, in this study, the utilization of OPMF as admixture material in CSB with different water-cement ratio was conducted. The aim of this study is to select the optimum water-cement ratio for the production cement sand brick with Oil Palm Mesocarp Fibre (OPMF) as admixture which meet the standard requirement and has a low thermal conductivity.

2. Materials and Method

2.1. Preparation of raw materials
The materials used in this study are Ordinary Portland Cement (OPC), sand, oil palm mesocarp fibre (OPMF) and water. The OPMF ware taken from Ladang Tereh Mill Kulim Plantation (M) Sdn. Bhd. located at Kluang, Johor, Malaysia. The fibre was treated by immersed with one portion of OPMF (g) and mixed with 20 portions (ml) of Sodium Hydroxide (NaOH) or 1% by weight for 30 minutes. The treated fibre then was washed with distilled water and oven dried at 50°C-60°C until constant weight [18]. The fibre was grinded into smaller pieces and surpasses sieved of 5 mm to ensure the particle size was uniform for brick manufacturing. Figure 1 shows the OPMF waste fibre with a treatment of NaOH.
2.2. Manufacturing process of bricks

In this study, six different mix ratio (cement: sand: fibre) were considered as shown in Table 1. For each ratio, 15 samples were manufactured. The nominal dimension for brick size is 225 x 113 x 75 mm as followed JKR Standard Specification for Building Work (2005) [19]. To produce a control brick sample, cement and sand were weighed and mixed first by using a mechanical mixer at 10-litre capacity. The same step was repeated to make OPMF brick, with an incorporation of constant 1.5% waste into the mixture. However, for fibre bricks, sand, cement and fibres were mixed first so that the fibres were evenly distributed before water was added. Then, the samples were pressed into moulds according to the shape and compacted further. The newly-produced raw bricks were dried naturally for 24 hours at room temperature before the curing process. Basically, the bricks have been cured for 7 days and 28 days by using wet blanket curing. The manufactured bricks then underwent a series of test including physical, mechanical, chemical and thermal properties.

Table 1. Material composition and ratio

| Sample  | Cement: sand: fibre<sup>a</sup> | Water-cement ratio |
|---------|-------------------------------|--------------------|
| 1 (Control) | 1:5:0 | 0.45 |
| 2       | 1:5:0.04 | 0.45 |
| 3       | 1:5:0.04 | 0.50 |
| 4       | 1:5:0.04 | 0.55 |
| 5       | 1:5:0.04 | 0.60 |
| 6       | 1:5:0.04 | 0.65 |

Note: 1 volume ratio of cement = 2.75 kg, 1 volume of sand = 3.25 kg.
Weighing was carried out using an electronic balance with a precision of 0.01 kg.
<sup>a</sup> Fibre ratio is in kg (corresponding to 1% of reference cement volume)

2.3. Properties of cement-sand brick

2.3.1. Physical and mechanical properties

All manufactured specimens were tested for sieve analysis, specific gravity, compressive strength and water absorption test. For compressive strength test, these testing were according to ASTM C129-06 (2006) [20]. While, for water absorption followed ASTM C67-94 [21].
2.3.2. Chemical composition

X-ray fluorescence (XRF) test was conducted for OPMF in order to determine its chemical compound.

2.3.3. Thermal conductivity

Thermal conductivity was tested using a hot guarded plate method follow the ASTM C177 [22]. This device can measure the thermal conductivity of a material when a layer of materials of known thickness and area are heated form one side by an output. This test likewise measures the ability of a material to conduct heat. Then, following the procedure of BS EN ISO 8990 (1996) [23], the experiment was kept running for 100 minutes for each specimen and the information was recorded for each one minute.

3. Result and discussion

3.1. Sieve analysis test

Sieve analysis test was done to obtain the particle size of the raw material. The particle sizes can be calculated based on the weight of soils loss when passing sieve size. The test was conducted based on BS 1377: Part 2: 1990 [24]. Based on the result obtained, the sieve analysis of the sand sample is presented in Figure 2.

![Figure 2. Sieve analysis of sand](image)

From Figure 2, more than 90% of the aggregate passed through sieve 4.75 mm which places the aggregate as a fine aggregate as BS882 (1992) [25] and the assessment of the particle size distribution revealed that the aggregate is well graded.

3.2. Specific gravity

The specific gravity (Gs) of a material is defined as the ratio of the weight (or mass) of a given volume of the material to the weight (or mass) of an equal volume of water. Gs is useful for determining weight – volume relationships. The result for the specific gravity of sand and OPMF were 2.65 and 1.17 respectively.

3.3. X-ray fluorescent analysis (XRF)

This test was conducted to obtain the various chemical compounds present in OPMF. Based on Table 2, it shows that the chemical compound for Zirconium dioxide (ZrO\textsubscript{2}) was the highest compound presence in OPMF waste. ZrO\textsubscript{2} is a white crystalline oxide of zirconium. Zirconia is produced by calcining zirconium compounds, exploiting its high thermal stability [26]. Hence, zirconia has to be compared with a material that is both aesthetic and has good mechanical properties for use as a restorative material [27] in brick manufacturing. Therefore, the presence of ZrO\textsubscript{2} tends to produce better properties of bricks.
Besides that, another compound such as Calcium oxide (CaO) contributes to the plasticity of the mix. It is additionally valuable in creating a very tenacious adhering power which helps the mix hold to forms and moulds.

Table 2. Chemical composition of OPMF.

| Chemical compound    | Formula | Concentration (%) |
|----------------------|---------|-------------------|
| Zirconium dioxide    | ZrO₂    | 12.20             |
| Carbon               | C       | 0.10              |
| Hafnium dioxide      | HfO₂    | 8.83              |
| Silicon dioxide      | SiO₂    | 7.62              |
| Iron oxide           | Fe₂O₃   | 4.60              |
| Calcium oxide        | CaO     | 3.47              |
| Potassium oxide      | K₂O     | 4.37              |
| Sulfur trioxide      | SO₃     | 1.03              |
| Chlorine             | Cl      | 0.80              |
| Aluminium oxide      | Al₂O₃   | 0.97              |
| Phosphorus pentoxide | P₂O₅    | 1.23              |
| Sodium oxide         | Na₂O    | 0.22              |
| Magnesium Oxide      | MgO     | 0.49              |
Figure 3. The compressive strength of specimen with different water-cement ratio

The content of water-cement ratio in the brick plays an important role in determining the compressive strength of the brick. Increasing of water-cement ratio ranging from 0.45 to 0.65 was found to impact the compressive strength of specimens significantly. From the graph, it shows that as the water-cement ratio increased, the compressive strength increased. This study is similar with [29] reveals that lower water-cement ratio reduces the workability and compressive strength due to the presence of air voids in bricks.

3.4.2. Effect of water-cement ratio to water absorption

Absorption measures the unit’s total capacity to absorb moisture. The results of percentage water absorption with a different water-cement ratio at 28 days curing time are shown in Figure 4. It can be conclude that the absorption of bricks increased as water cement ratio increased. This is due to the high amount of water that helps on bonding and reaction process of bricks. The present of OPMF fibre needs more water for hydration process and voids inside the bricks have the tendency to absorb more water during immersion of the brick. Overall, water absorption for the brick with 0.65 has the highest water absorption value (1.99%). However, it is meet the standard requirement that is lower than 18%.

Figure 4. The average water absorption between different water-cement ratio

3.4.3. Effect of water-cement ratio to thermal conductivity

Figure 5 shows the result for thermal conductivity of bricks. The result shows that the thermal conductivity of bricks decreased as the water-cement ratio increased. That is due to the porosity of fibre brick that played an important role in determining the value of thermal conductivity. Porosity influences the value of thermal conductivity because of the existence of space and voids between brick particles. Therefore, from the comparison between a different water-cement ratio of bricks, it can be concluded that the water-cement ratio influenced the value of thermal conductivity. The results were
also below the maximum requirement of ASTM C177 which are 1.16 W/m°C. The lower of thermal conductivity improves the insulation properties of a brick wall.

Figure 5. Effect of different water-cement ratio on thermal conductivity

4. Conclusion
The production of OPMF waste has been an issue in the palm oil industry. Often the accumulating wastes were not reused and disposed into landfills and caused another environmental issue. OPMF was worth being recycled as bricks as this could lessen the disposal problem and pollution apart from becoming a building material. The utilization of OPMF waste into bricks could act as a low thermal brick that provides an alternative solution for low consumption energy and improves the comfort in buildings. The OPMF waste could also be a potential for a low-cost waste admixture for the production of brick. In conclusion, it can be found that the different water-cement ratio gives a different compressive strength, water absorption and thermal conductivity to bricks. Meanwhile, air dry curing process brings a positive effect to the increasing strength of bricks. Therefore, water-cement ratio of 0.65 was selected as the optimum ratio for further manufacturing of OPMF brick as it fulfils the standard requirement.

5. References

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