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# Influence of marine kaolin mortar mixed with effective microorganism on external heat transfer

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# Influence of marine kaolin mortar mixed with effective microorganism on external heat transfer

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**Abstract.** Marine kaolin can be found easily at the coastal regions in Malaysia. During infrastructure works, huge quantities were excavated and is treated as unsuitable soil material (USM). This study offers a value-added solution to convert marine kaolin into supplementary cementitious material (SCM) through thermal activation. 10% replacement of Ordinary Portland Cement is incorporated together with Effective Microorganism (EM) into the mortar mix. The usage of EM between 5% and 25% with interval of 5% were manipulated to enhance the properties of the mortar mix. The intention of incorporating both marine kaolin and EM as mortar mix was to observe the significant effects on heat transfer. As a result, the surface temperature of the mortar mix was reduced up to 8% and the thermal conductivity shows appropriate insulating materials.

## 1. Introduction

The usage of cement is increasing exponentially for strong and durable structures. As the cement production increases, the emission of $CO_2$, a major greenhouse gas, increases [1]. Based on several reports by the Kyoto Protocol, IPCC (2006) and UNEP (2010), $CO_2$, is the most important anthropogenic greenhouse gas. Basically, the raw materials for producing cement operate at a higher peak temperature of about 1500°C [2].

In such a scenario, any technology that would reduce the consumption of cement can contribute significantly to the health of environment [1]. It will be economically beneficial if reduction in the amount of cement by providing some alternate material such as partial replacement of cement by industrial waste which is hazardous to the environment [3].

A rapid development in the production of less energy intensive cements and concretes with high performance (resistance and durability) has occurred. This has been accomplished by the use of industrial wastes or by-products (fly ash, slag, silica fume, rice husk) with considerable pozzolanic activity. The use of those secondary materials results in improvements in durability and strength enhancement. For example, Yang et al., (2013) used fly ash and furnace slag for stabilization of soil and produced new low strength construction material by autoclave curing [4].

Recent studies are focusing on thermally activated clays as potential sources for pozzolanic materials as well as incorporating live bacteria into concrete/cement mortar for high-performance construction materials. According to Yatim et al., (2015) the construction industry has been looking into using biological material such as microorganisms as the admixture for concrete [5].

Ismail et al., (2014) reported a review of previous researches related to the influence of incorporating Effective Microorganism (EM) into the cement-based material [6]. From the review, it 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 [7]. Besides, the reaction occurs between water and cement is mostly exothermic which generate heat [8]. Reason why any construction materials that have cement as its chemical composition, will give effects on its temperature and towards its surrounding environment. Existing mortar in markets have high absorption of heat and high heat storage capacity, thus increasing the temperature on its surface and its surrounding temperature. By incorporating EM with marine kaolin as mortar, it will reduce the heat absorption and the heat capacity of the induced material. Thus, providing cooler surface finishing and reducing the temperature of its surrounding environment. Therefore, this study is to determine the influence of marine kaolin mortar mixed with EM on heat (surface temperature and thermal conductivity).

## 2. Materials and Methodology

The materials used for this study were marine kaolin, cement and Effective Microorganism (EM). Marine kaolin is collected from a construction site at Tanjung Bin, Gelang Patah, Johor, Malaysia. There are two samples collected from different location, namely; CH300 (Sample 1) and CH6700 (Sample 2). 3kg of each samples were grinded in Los Angeles Abrasion Machine (LA) of 10,000 cycles to have required grain size of 4.75 micron as similar to cement particles. The cement used is Ordinary Portland Cement (OPC) – ASTM Type 1 with specific gravity of 3.15 g/cm$^3$. Percentage of EM is manipulated in the range of 0% (control mortar) till 25% with an increment of 5%, respectively. The data collection are obtained by conducting two testing, which is the surface temperature and thermal conductivity.

### *2.1. Preparation of Marine Kaolin Mortar Mixed With EM*

The mortar mix was prepared using sand and cement ratio of 3:1 by weight and EM at W/C ration of 0.55. Figure 1 shows the mixing of materials were done manually with the mix proportion as shown in Table 1 and thickness of 10mm mortar was laid on top of concrete block with dimension of 225 x 112.5 x 75 mm (length x depth x height).

(a) (b) (c)

**Figure 1**. (a) Mixed materials with water and EM, (b) 10mm mortar thickness and (c) mortar with different percentage of EM.

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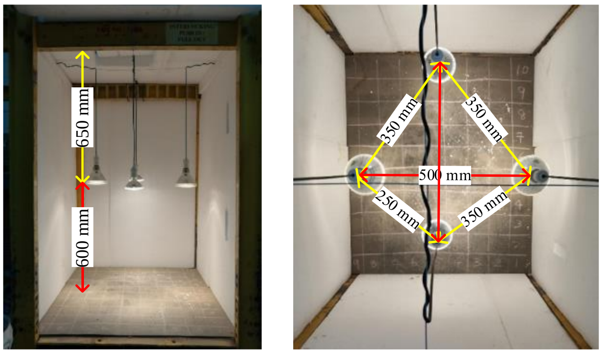
**Table 1**. Mix proportion of marine kaolin mortar mixed with EM.

| % of EM from water | Water (g) | EM (g) | Cement (g) | Sand (g) | Kaolin Clay (g) | |
|---|---|---|---|---|---|---|
| | | | | | Sample 1 | Sample 2 |
| 0 | 512.33 | 0.00 | 838.35 | 2794.50 | 93.15 | 93.15 |
| 5 | 486.71 | 25.62 | 838.35 | 2794.50 | 93.15 | 93.15 |
| 10 | 461.10 | 51.23 | 838.35 | 2794.50 | 93.15 | 93.15 |
| 15 | 435.48 | 76.85 | 838.35 | 2794.50 | 93.15 | 93.15 |
| 20 | 409.86 | 102.47 | 838.35 | 2794.50 | 93.15 | 93.15 |
| 25 | 384.25 | 128.08 | 838.35 | 2794.50 | 93.15 | 93.15 |

### *2.2. Insulated Polystyrene Box*

Insulated polystyrene box were built to simulate the outdoor surrounding temperature during peak temperature in a day. Based on outdoor surrounding temperature data collection, the highest temperature of 49.8°C was recorded. Before testing, the box is under temperature conventioning of 4 hours until it achieved the required surrounding temperature of 50°C. Four LED type PAR38 100W bulbs were used in the box with dimension of 1m x 1m x 1.5m height (Figure 2). Figure 3 shows the heat distribution in the insulated polystyrene box.




(a) (b)

**Figure 2**. (a) Bulbs height and (b) bulbs position.

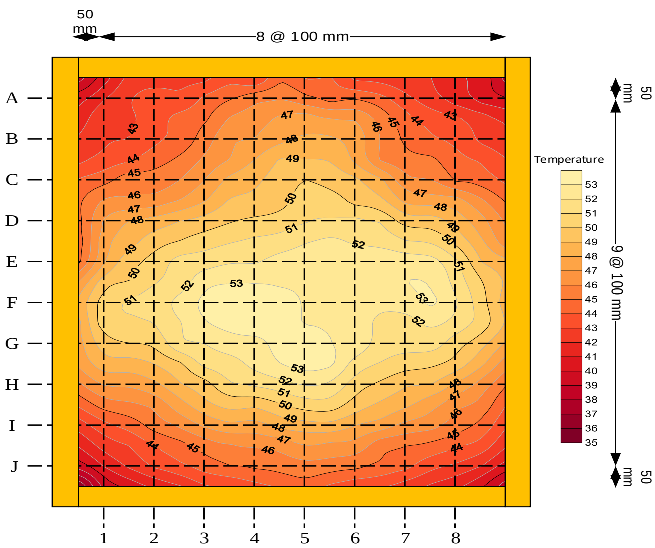
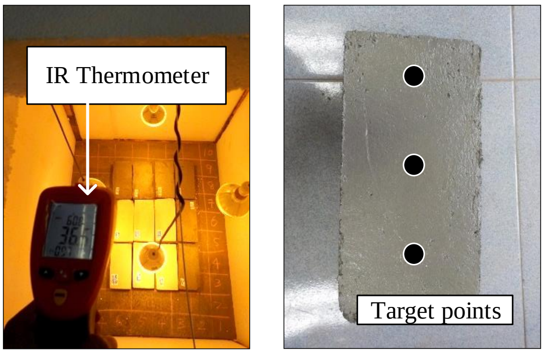



**Figure 3**. Heat contour.

### *2.3. Surface Temperature*
Surface temperature of the samples were taken by using Dual Laser InfraRed (IR) Thermometer. The testing is based on the FDA-recognized consensus standards, ASTM E1965-98 Standard Specification for Infrared Thermometer for Intermittent Determination of Patient Temperature [9]. Figure 4 shows the temperature measurement data collections. Three target points were taken on each sample and was tabulated.




(a) (b)

**Figure 4**. (a) Data collection by using IR thermometer and (b) target points in each sample.

### *2.4. Thermal Conductivity Test*
Thermal conductivity is the ability of a material to transfer heat where all the three heat transfer mechanisms are taken into account since the calculations are quite similar, and this is described by Fourier's law [10]. The measurement of thermal conductivity includes the measurement of the hat flux and temperature difference [11].

Three specimens' plate of 290 x 290 x 25mm thick were measured using a heat flow meter (HFM436) at temperature of 50°C, according to ASTM C 518 as shown in Figure 5. The three specimens were Sample 1 (CH300 EM25%), Sample 2 (CH6700 EM10%) and Control. These specimens have the lowest surface temperature thus, were chosen for further characterization.


(a) (b) (c)

**Figure 5**. (a)Apparatus calibration, (b) ready sample and (c) recorded data.

## 3. Results and Discussion

### *3.1. Surface Temperature*

*3.1.1. Sample 1 (CH300).* Based on Figure 6, EM of 10%, 15% and 20% gave higher surface temperature compared to control (EM 0%) while EM 5% and 25% gave lower surface temperature. The lowest surface temperature recorded was from marine kaolin mortar with EM percentage of 25%. The percentage difference calculated between control sample and EM25% was the highest compared to others with the range of 4 to 6%. This shows that the optimum EM percentage when mixed with marine kaolin Sample 1 was at 25%. As finding, the analysis data shows contradiction from previous study by [12] that stated EM with 5% shows the highest performance in compressive strength when compared to others in all maturity ages (28 days). However, they also indicated that by adding 25% EM and beyond, the tensile strength is higher compared to the lower dosage, while the development of compressive strength was retarded.

Notice that the surface temperature of all samples was linearly increased by days. This indicate that the reaction between marine kaolin mortar Sample 1 with EM was exothermic even after 28 days. It can be concluded that marine kaolin Sample 1 shows similar properties as in cement but gives different response effects. A study by Zhou et al., (2017) proves that London clay can be calcined to form a technically viable supplementary cementitious material, that have better result at 28-day strength as using cement in concrete but produces 27% lower embodied carbon [13].

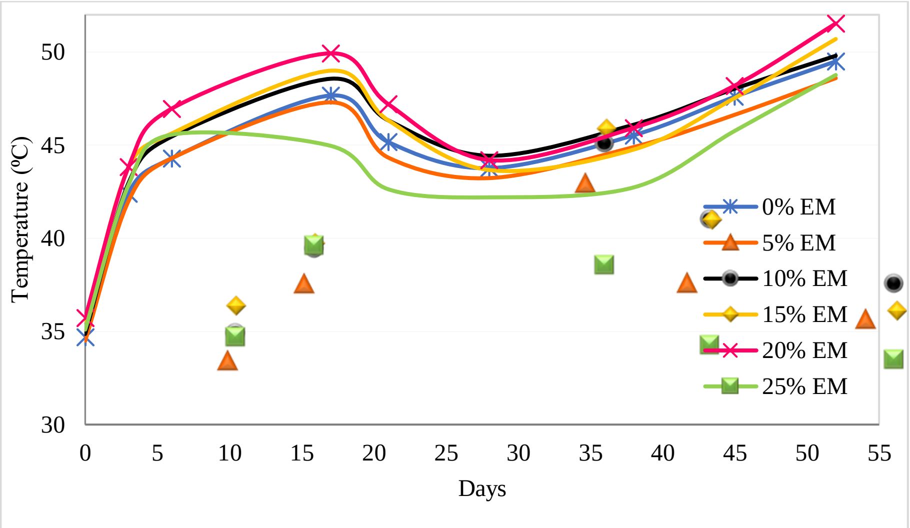



**Figure 6**. Temperature distribution of Sample 1.

*3.1.2. Sample 2 (CH6700).* Figure 7 shows that the surface temperature of all marine kaolin mortar mixed with EM gave lower value than control sample. This proves that by incorporating EM in mortar mix, gives cooler surface temperature compared to the surrounding temperature. It also shows that the lowest surface temperature recorded was marine kaolin mortar with EM10%. The percentage difference was the highest of 6% up to 8%. This indicated that the optimum EM percentage when mixed with marine kaolin Sample 2 (CH6700) was at 10%. The result shows significant value as stated in previous study by [14]. According to Ismail and Mohd Saman, (2014), the addition of EMMS of 10% in cement paste contribute to high increment up to 1.2 time (120%) of compressive strength respect to control at the age of 28 days [14]. In addition, the pattern of the surface temperature recorded was not consistent after 28 days. This indicates that the bacteria's present in EM was reacting with marine kaolin mortar. The probability of organic matters present in marine kaolin Sample 2 was high due to its moisture content at 130% compared to Sample 1 which at 70% only. The samples' location between the two samples differs. Sample 2 was 1 meter deep below the ground while Sample 1 was at 3 meter deep. Different excavation location and depth will give slightly different mineralogy and geotechnical properties of the marine kaolin. This can be proven through a study by [15] that classifies the engineering properties of the Singapore marine clay through three different layers; upper marine clay, intermediate stiff clay and lower marine clay.

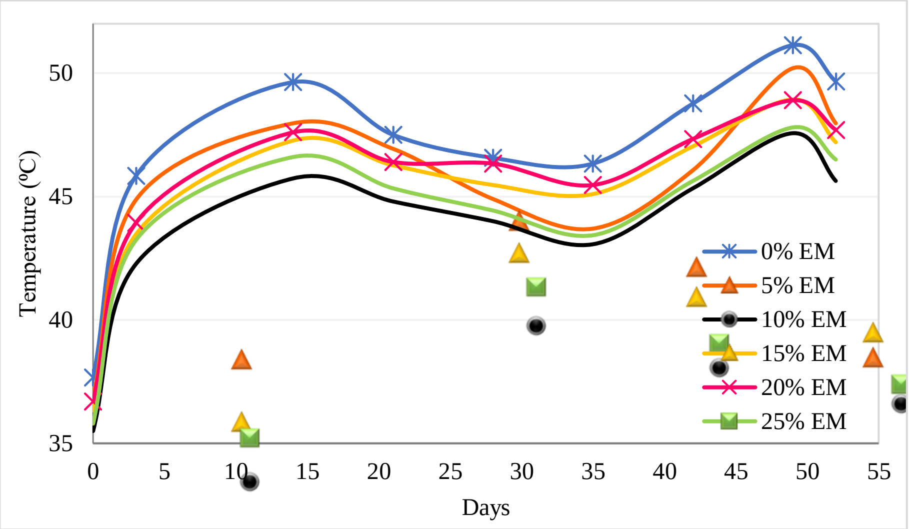



**Figure 7**. Temperature distribution of Sample 2.

*3.2. Comparison Between Kaolin Mortar Mixed with EM (Sample 1, Sample 2) and Cement.*

Figure 8 shows the tabulated temperature between marine kaolin mortar mixed with EM and cement mortar compared with control sample. As a result, marine kaolin mortar mixed with EM gave lower surface temperature compared to cement mortar. Both marine kaolin mortar show great difference in surface temperature after 28 days.

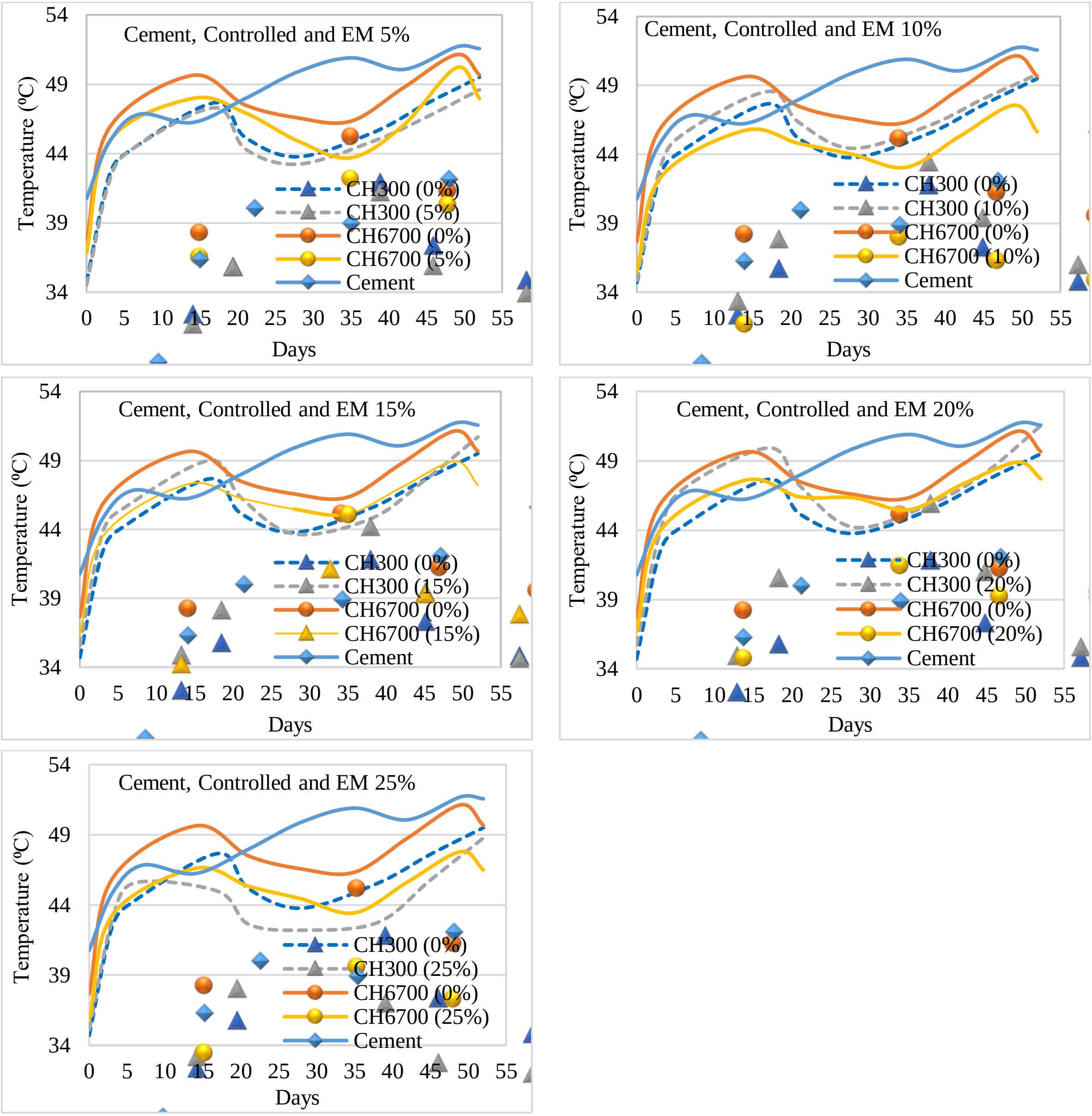



**Figure 8**. Comparison of surface temperature between three samples by different EM percentage with control sample.

### *3.3. Thermal Conductivity Test*

Thermal conductivity is heat-energy transfer from an element to other elements known as particle interactions. To put it simply, the thermal conductivity of the mortar samples show how fast the mortar samples cool down at various internal and external temperatures. The lower the number, the better insulation qualities it has [16]. Table 2 and Figure 9 show Sample 2 has the lowest thermal conductivity value when compared to cement mortar. It is confirmed that the thermal conductivity will increased linearly with density. The thermal conductivity is not always constant. The main factors affected the thermal conductivity are the density of material, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases too [17].

**Table 2**. Thermal conductivity results.

| Sample ID | Material Description | Density (kg/m³) | Mean Temperature (°C) | Delta Temperature (°C) | Thermal Conductivity k (W/mK) | Thermal Resistance ϕ (2K/W) | Temperature Gradient (K/m) |
|---|---|---|---|---|---|---|---|
| CH300 | EM 25% | 1843.95 | 50.11 | 19.87 | 0.193501 | 0.153497 | 669.10 |
| CH6700 | EM 10% | 1838.53 | 50.70 | 19.94 | 0.186884 | 0.156139 | 683.41 |
| Cement | Cement Mortar | 1821.64 | 50.04 | 19.94 | 0.225570 | 0.124836 | 708.16 |

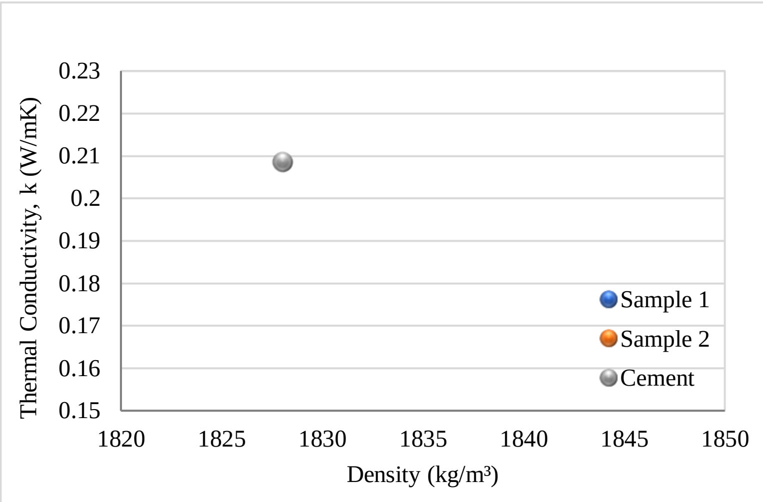



**Figure 9**. Thermal conductivity vs density.

## 4. Conclusion

This study conclude that surface temperature and thermal conductivity of marine kaolin mortar mixed with Effective Microorganism (EM) gives somes effects as follows:

i. Optimum percentage of EM Sample 1 and Sample 2 is varied. Sample 1, the optimum percentage of EM is 25% while Sample 2 is 10%. This probably due to reaction occurred between the organic matter present in marine kaolin with EM and cement.

ii. Although Sample 1 shows inconsistency in data collection, it does have the lowest surface temperature value compared to Sample 2 and cement mortar. This shows that Sample 1 can be used as possible building materials in the future.

iii. Thermal conductivity from three samples indicate Sample 2 with the lowest value compared to others. This shows that Sample 2 has better insulation qualities and can be good insulator for building materials.

iv. Incorporating marine kaolin with EM does give significant effect in lowering the surface temperature compared to cement mortar.

Although many studies have shown potential applications of EM utilized in concrete and the usage of marine kaolin as substitution of soil through stabilization, further investigations should be carried out to determine its suitability as marine kaolin mortar for thermal activation effects. It is observed that marine kaolin mortar mixed with EM can be used as future building materials but more research is required to address the issues of corrosion, durability and strength of the mix.

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