Conference Paper

# Thermal Performance of Plastered Bamboo-Wall

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## Abstract

This paper reviews the application of plastered-bamboo wall (PBW) as an alternative wall construction to replace a conventional brick wall, that are evaluated based on thermal aspects. Brick as the material which is composed of a wall has a high value of density. High-density materials generally have a great heat capacity and contribute to raising the ambient air temperature. On a large scale, they can trigger the occurrence of a heat island phenomenon (UHI). PBW is a technique of wall construction, which are composed of bamboo as a frame and mortar as a frame cover. The thickness of the PBW ranges from 5 to 9 cm. PBW has a lower value of density than a brick wall. This study aims to test the thermal performance of PBW based on its constituent framework, which is divided into two groups of specimens, namely; bamboo woven, and bamboo array. The samples were tested in the field and arranged in such a way as to be exposed to solar radiation. In practice, the heat capacity of specimens was identified through its density. Meanwhile, the thermal performance of samples was identified through time lag (TL) by using thermocouple and globe thermometer. All the results indicate that specimens with bamboo array have better time lag value (longer time) than all specimens with bamboo woven.

**Keywords:** material density, plastered-bamboo wall, thermal performance, time lag, wall construction

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## 1. Introduction

Bricks and concrete are building materials commonly used as building components. This is based on the ease of construction and low maintenance costs. The use of both materials in building are quite significant, since the increase of occupancy needs [1]. The use of those materials in building have an effect on increasing the temperature around it, and on a larger scale, can trigger UHI. Bricks and concrete have large material density. Materials with a large density, will be directly proportional to the value of a large material thermal conductivity [2]. In this case, solar radiation which is received by the materials will be absorbed and released back to the surrounding environment with large intensity.

Therefore, alternative materials are needed to minimize the negative effects of heavy materials, one of which is the use of bamboo materials.

Bamboo is a sustainable material and its availability is quite abundant in Indonesia, especially in Java island. Bamboo growth rates are very fast, where the average daily growth is around 20 cm to 100 cm [3-4]. Within 2-4 months, it can reach heights of 15-30 m, and at the age of 3-5 years bamboo can be harvested [4]. Utilization of bamboo is still limited to decorative components, but can also be a structural component in simple dwellings or as a scaffolding for building construction [5]. This is based on the problem of durability of bamboo. In Indonesia, the use of bamboo for houses is usually found in sub urban areas or traditional settlements. In this case, bamboo is still considered as a simple material and is not in accordance with current development needs.

In Indonesia, the use of bamboo as a building material for wall had been applied during the Dutch colonial era, where bamboo was used as wall frame and mortar as frame cover, or now better known as composite bamboo. In some countries such as; India, Philippines and Colombia also use bamboo as a building material for building components, especially the walls of houses in sub urban areas, and better know as PBW [6]. The frame cover contribute to maintain the durability of bamboo and gives an impression of the wall. This is a good potential, so that bamboo can be applied to buildings.

Based on its characteristics, PBW has a thickness of about 5 - 9 cm. A frame made of bamboo woven, in west java it called *sasak*. In thermal aspect, the thickness will greatly affect the temperature of room in the buildings. Meanwhile, the wall with bricks has a thickness of about 15 cm, and until now it is still considered the most comfortable as a building wall. The aim of this study is to measure the thermal performance PBW and optimize its thermal performance by extending the TL of the PBW. The addition of bamboo mass is predicted to be able to extend the TL of the PBW.

## 2. Methods

This study is an experimental study by testing the specimens in the field. This study examined five specimens of PBW with a size of 680 x 600 mm, to compare the thermal performance between specimens with bamboo woven and specimen with a bamboo array. Table 1 below indicates all specimens that are tested, and table 2 shows the technical testing design. The bamboo panels which are tested consist of bamboo with the outer shell (cuticle [6]) and non-cuticle bamboo panels.

Table 1: The Specimens of plastered bamboo.

| **Bamboo woven + *cuticle*** | **Bamboo woven + non-*cuticle*** | **Bamboo array** |
|---|---|---|
| 1 | 3 | 5 |
|  |  |  |
| 2 | 4 | |
|  |  | |

Table 2: Technical testing.

| Measurement | Instruments | Procedure | PBW Specimens | Time | Indicators |
|---|---|---|---|---|---|
| 1. Surface Temperature | Thermocouple | | Woven bamboo panels, | | Time Lag & Thermal Capacity |
| 2. Radiant Temperature (For verification) | Globe Thermometer | Field test | Array bamboo panel | 08:15 - 08:15 (24 Hours) | |


**Figure** 1: 1.Thermocouple, 2. Globe Thermometer.

TL is the time that is required for maximum or minimum temperature waves to propagate through the wall, from outer to the inner surface [7]. Then through TL can be known the value of decrement factor (DF). DF is the ratio between the peak ratio of the outer surface temperature and the internal surface temperature based on the average daily temperature [8]. The smaller the DF value (approaches zero), the better the thermal performance. In general, the higher the TL, the better thermal performance [9]. The relationship between TL and thermal capacity (TC) are as follow, TL can increase when TC increases, while DF decreases when TC increases [10]. DF approaches zero when the thermal capacity is quite large [10].

Meanwhile, the effect of wall thickness concerning TL and DF is, TL will increase if the thickness of the material is higher, while DF decreases, where the thickness is greater [10]. The relationship between TL and thickness is linear [10]. Actually, by increasing wall thickness, thermal resistance also increases; however on the other hand thermal capacity will also increase [10].

$$\text{decrement factor } (\mu) = \text{Ti max}/\text{To max} \tag{1}$$

The Specimens of PBW were tested in the field and placed facing the sun. Specimens are arranged in such a way on a simple building to get solar radition with same intensity. Measurement of time lag was identified through the heat propagation rate from outer surface temperature (OST) to inner surface temperature on each specimen for 24 hours.


**Figure** 2: Field testing.

# 3. Results

## 3.1. Time lag and decreament factor

### 3.1.1. Specimen 1

The graph below (Figure 3) shows TL based on the peak of surface temperature on the specimen 1, where the temperature rise of the OST starts at 05:15, as well as the IST, raised which begins at 05:15.

On the specimen 1, the peak of OST occurred at 08:15, with a temperature of 43.6 °C, while the peak of IST occurred at 11:25, with a temperature of 32 °C. The difference of the peak temperature of OST and IST is 11.6°C. The specimen 1 has TL during 3:12:00 and DF (μ): This max / Tos max = 32 / 43.6 = 0.73

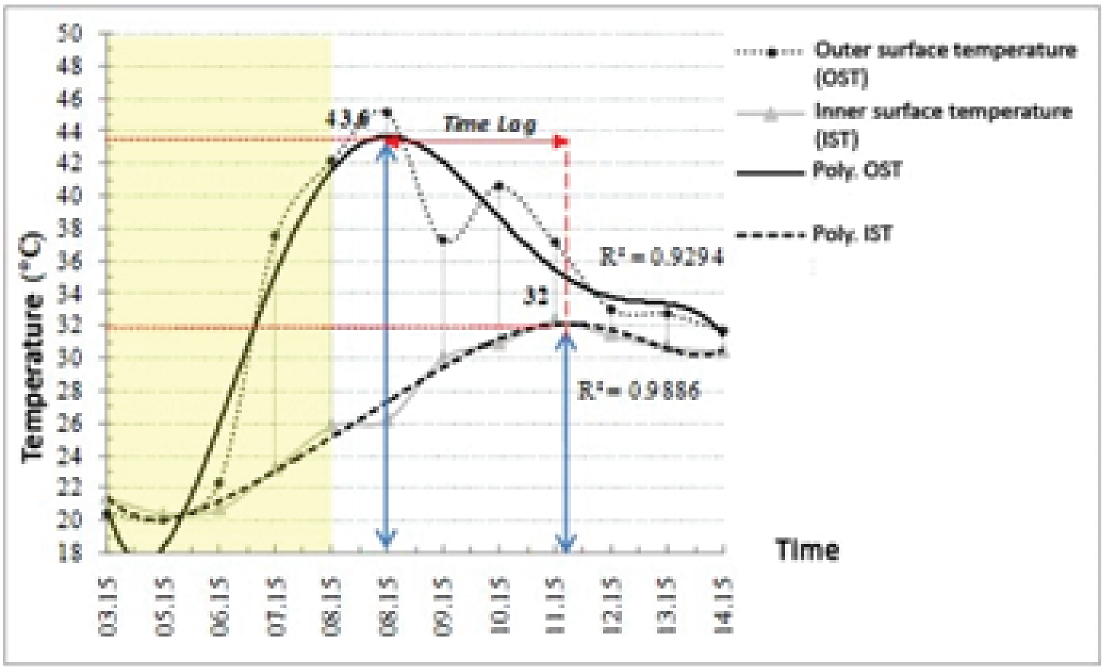


**Figure** 3: Time lag of specimen 1.

### 3.1.2. Specimen 2

On the specimen 2, the temperature rise of OST occurred a little faster, which is at 04:00. Meanwhile, the line pattern on the graph that shows the beginning of the temperature rise of IST occurred at the same time specimen 1 and specimen 3, that is at 05.15. Based on the graph (Figure 3), the OST at its peak occurred at 08:15, with a temperature that almost the same as the peak temperature of the OST of specimen 1, which is 43.8 °C.

Meanwhile, the IST at its peak occurred at 11:45, with a temperature of 32.1 °C. The difference between the peak temperature of OST and IST is 11.8°C. TL of the specimen 2 during 3:24:00 with decrement factor (μ): Tis max / Tos max = 32.1 / 43.8 = 0.73

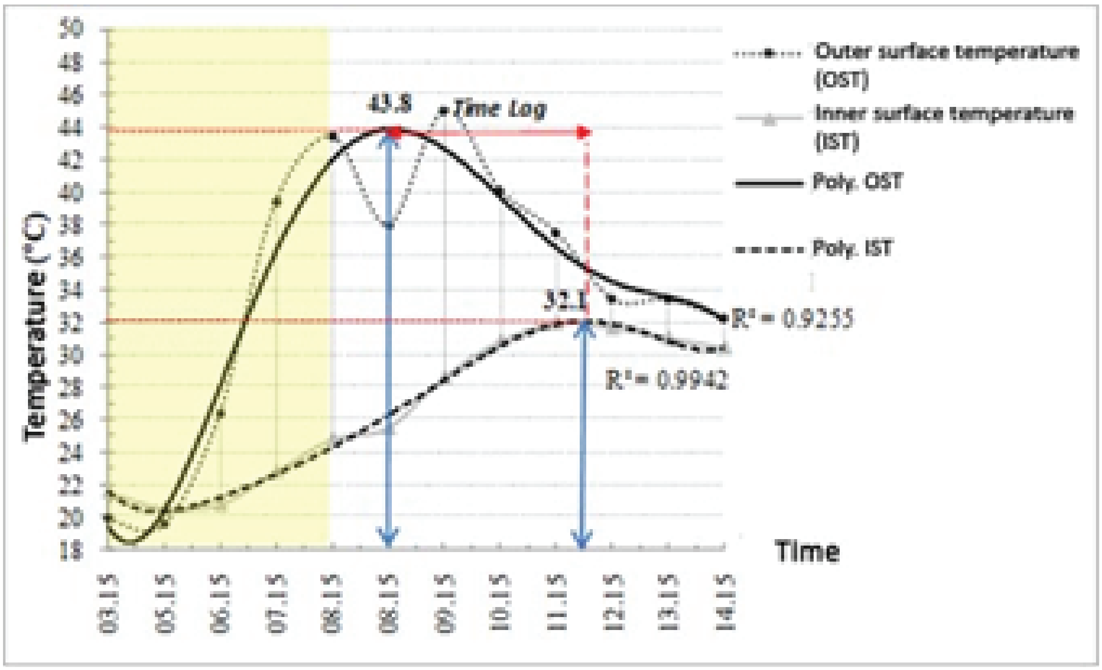


**Figure** 4: Time lag of specimen 2.

### 3.1.3. Specimen 3

The graph of TL on the specimen 3, began with the temperature rise of OST that occurred a little slow than the specimen 1, which is at 05:25, while the temperature rise of IST which occurred at the same time, which is at 05.15. The specimen 3 has the peak point of the OST which occurred at 08.30, with a slightly higher temperature, which is 45.1 °C. While the peak point of IST occurred at 11:10, with a temperature of 33.1 °C. Difference of the peak temperature of OST and IST is 12°C, with TL of 2:36:00. The specimen 2, has the same decrement factor (μ) value as the specimen 1, namely: Tis max / Tos max = 33.1 / 45.1 = 0.73.

### 3.1.4. Specimen 4

The TL of specimen 4, began with the temperature rise of OST and the initial rise of IST which is relatively the same as the specimen 1, which occurred at 05:15. The specimen 4 has a higher peak surface temperature compared to another specimen of PBW with bamboo woven. The peak of the OST occurred at 08.40, with a temperature of 46.3 °C.

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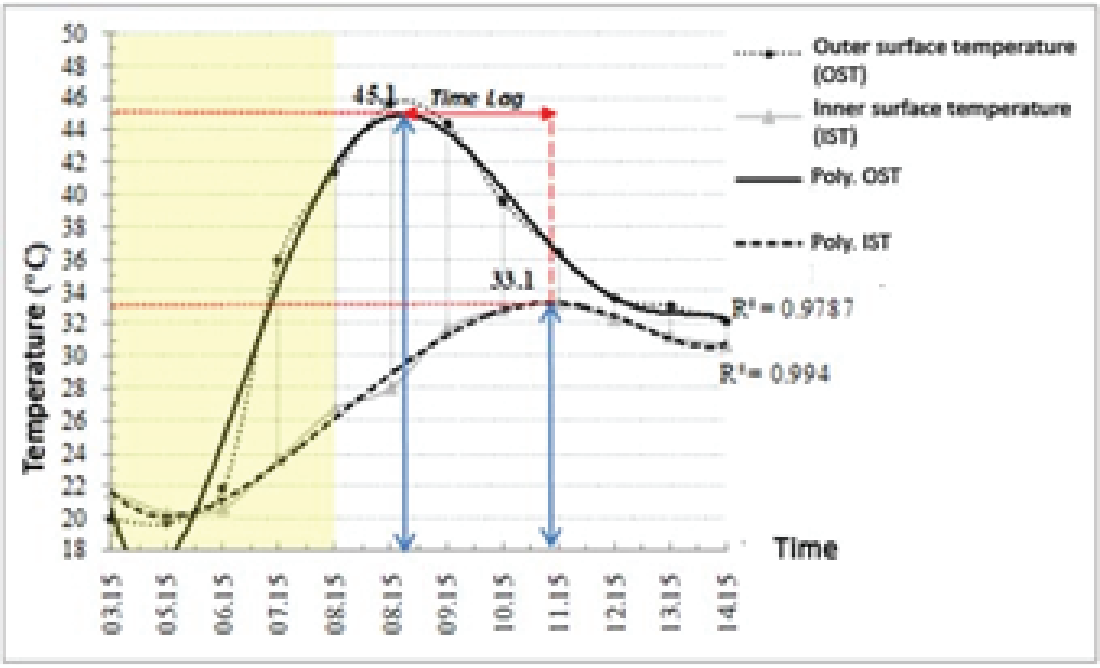


**Figure** 5: Time lag of specimen 3.

Meanwhile, the peak of IST occurred at 11:25, with a temperature of 32.8 ˚C. Therefore, the difference in the peak of the OST and IST is 13.5˚C, with TL of 2:48:00. However, having a slightly better decrement factor (μ) value, namely: Tis max / Tos max = 32.8 / 46.3 = 0.70.

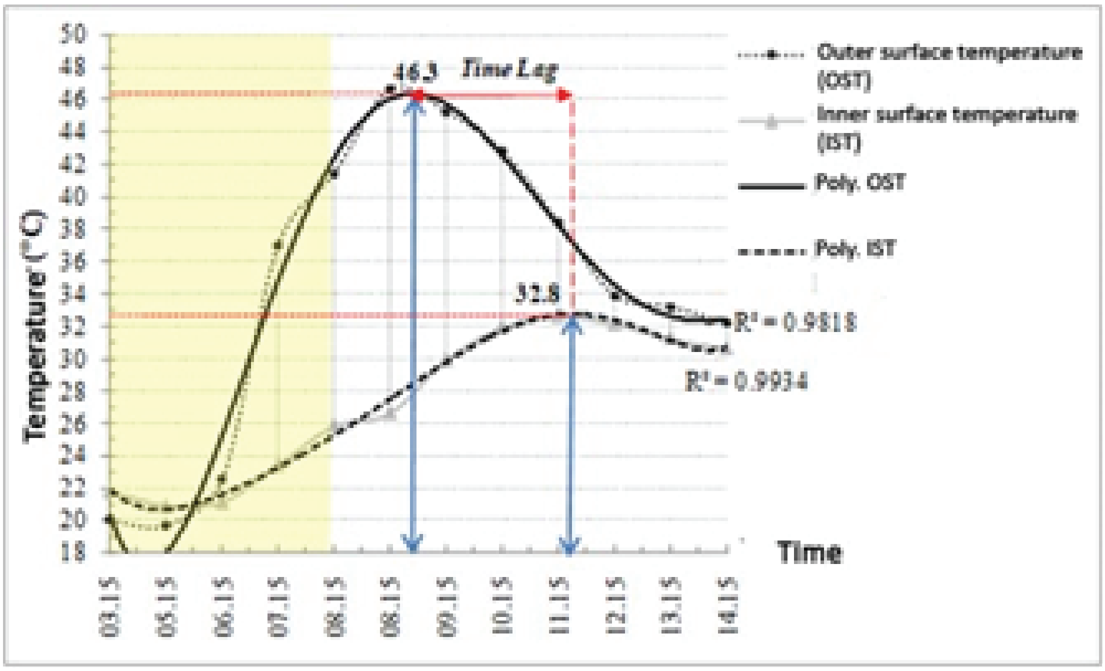


**Figure** 6: Time lag of specimen 4.

### 3.1.5. Specimen 5

The graph of TL on specimen 5 has a higher peak surface temperature compared to all specimen with bamboo woven. The Initial of the temperature rise of OST occurred at 05:45, while the temperature rise of IST occurred at 05:35. The peak temperature of the OST on the specimen 5, occurred at 08.05, with a temperature of 48.9 °C, while the IST at its peak occurred at 12.15, with a temperature of 29.9 °C. The difference of the peak temperature of OST and IST is greater, namely 19°C. That affects its time lag, which is 4:12:00. Decrement factor (μ) specimen 5: Tis max / Tos max = 29.9 / 48.9 = 0.61.

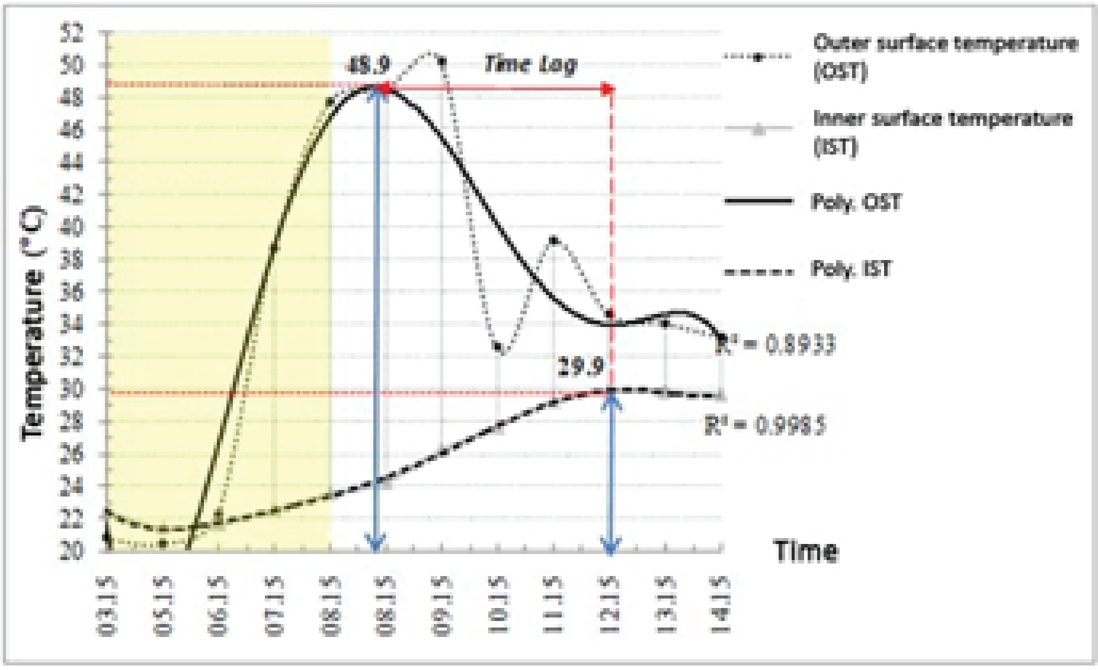


**Figure** 7: Time lag of specimen 5.

## 3.2. Density of specimens

Table 3 shows the density ratio of each specimen. Based on a comparison of the density of the specimens, the specimen 5 has a small density value. Specimen 5 has a larger thickness. However, the density is lesser, because it consists of a more massive bamboo array. These conditions affect the intensity of heat release. In this case, the capacity to store heat is more significant, however, the heat released is smaller. Specimen 1 has a higher density than the specimen 3, while the specimen 2 has a higher density than the specimen 4.

TABLE 3: Density comparison of specimens.

| Specimens | Figures | Density |
|---|---|---|
| Specimen 1 |  | Mass of bamboo = 1,6 kg<br>Mass of mortar = 51,43 kg<br>**Total mass : Bamboo + mortar = 53,3 kg**<br>Volume of bamboo = 0,00192 m$^3$<br>Volume of mortar = 0,0245 m$^3$<br>**Total Volume : Bamboo + mortar = 0,026 m$^3$**<br>**Density :**<br>$\rho = \frac{m}{v} = \frac{53}{0,026}$ = 2.039 kg/ m$^3$ |
| |  | Mass of bamboo = 1,58 kg<br>Mass of mortar = 51,43 kg<br>**Total mass : Bamboo + mortar = 53,01 kg**<br>Volume of bamboo = 0,003 m$^3$<br>Volume of mortar = 0,06 m$^3$<br>**Total Volume : Bamboo + mortar = 0,0275 m$^3$**<br>**Density :**<br>$\rho = \frac{m}{v} = \frac{53,01}{0,0275}$ = 1.928 kg/ m$^3$ |
| Specimen 3 |  | Mass of bamboo = 1,64 kg<br>Mass of mortar = 51,43 kg<br>**Total mass : Bamboo + mortar = 53,07 kg**<br>Volume of bamboo = 0,0024 m$^3$<br>Volume of mortar = 0,0245 m$^3$<br>**Total Volume : Bamboo + mortar = 0,0269 m$^3$**<br>**Density :**<br>$\rho = \frac{m}{v} = \frac{53,07}{0,0269}$ = 1.973 kg/ m$^3$ |
| Specimen 4 |  | Mass of bamboo = 1,48 kg<br>Mass of mortar = 51,43 kg<br>**Total mass : Bamboo + mortar = 52,91 kg**<br>Volume of bamboo = 0,0037 m$^3$<br>Volume of mortar = 0,0245 m$^3$<br>**Total Volume : Bamboo + mortar = 0,0282 m$^3$**<br>**Density :**<br>$\rho = \frac{m}{v} = \frac{52,91}{0,0282}$ = 1.876 kg/ m$^3$ |
| Specimen 5 |  | Mass of bamboo = 7,1 kg<br>Mass of mortar = 51,43 kg<br>**Total mass : Bamboo + mortar = 58,53 kg**<br>Volume of bamboo = 0,012 m$^3$<br>Volume of mortar = 0,051 m$^3$<br>**Total Volume : Bamboo + mortar = 0,063 m$^3$**<br>**Density :**<br>$\rho = \frac{m}{v} = \frac{58,53}{0,063}$ = 929 kg/ m$^3$ |

## 4. Discussion

The graphs below (Figure 8 and 9) shows the difference in range between the peak of OST and the peak of IST. The greater the difference value indicates the small value of the heat propagation rate. In this case, there was the heat that was suspended or delayed in the specimens. In general, specimen 5 has a longer TL compared to all specimens with bamboo woven. DF (μ) of specimen 5= 0.61. This value shows that the specimen 5 has better heat resistance than all specimens with a bamboo woven.

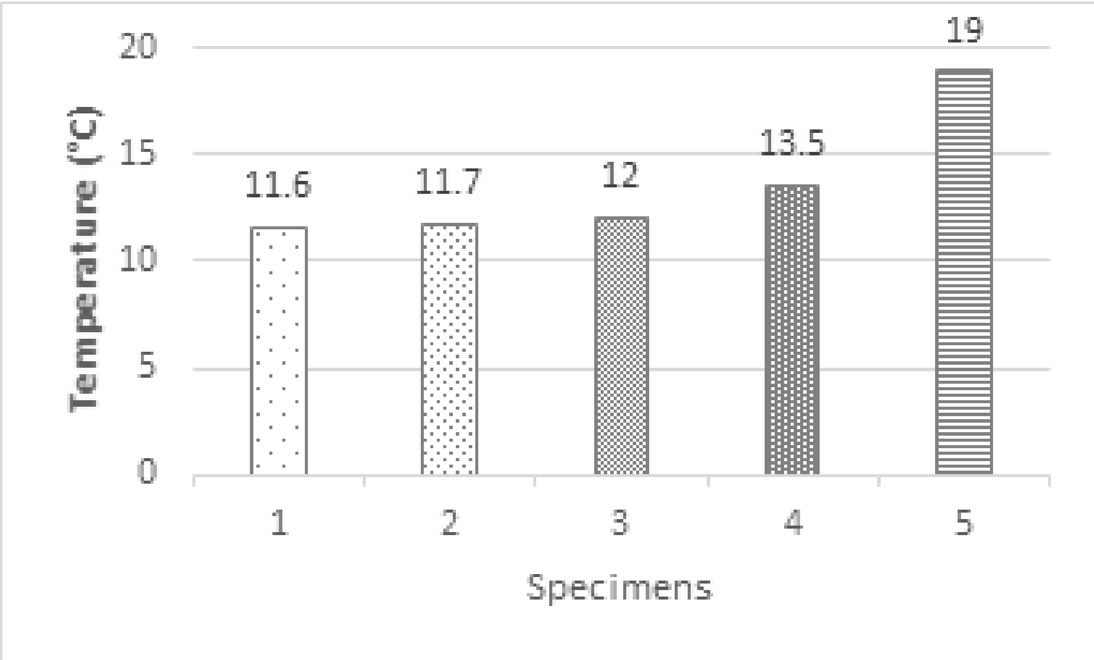


**Figure** 8: Comparison of peak temperature difference.

The difference in heat rate (Figure 10), gives a representation of the distance range between the average rate of OST and IST. The greater the difference value, indicates the slowing of the heat rate.

Material density plays a role in the heat release process. In general, specimen 5 has a longer heat mass delay, with a slowing of heat rate. The total thickness of the specimens is the main factor in the process. It gives more understanding that the cuticle on the bamboo has an effect on the process of heat delay and heat release.

## 5. Conclusions

Based on the thermal aspect, the specimen 5 with bamboo array has a better thermal performance for heat delay and heat release. A more extended time lag value indicated it

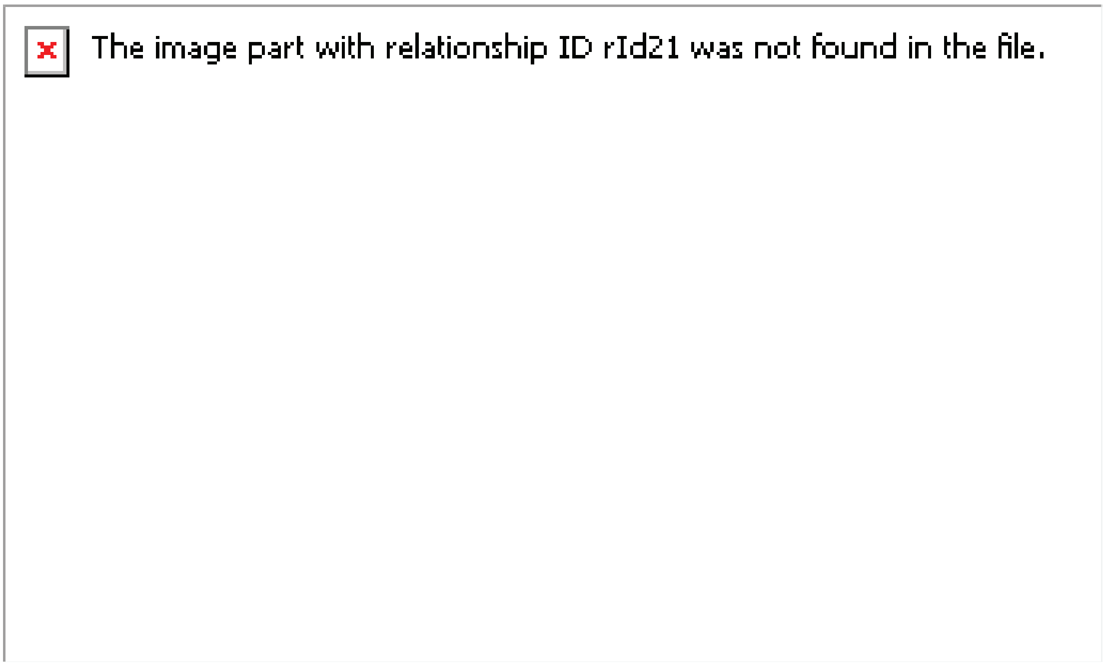


**Figure** 9: Comparison of time lag.

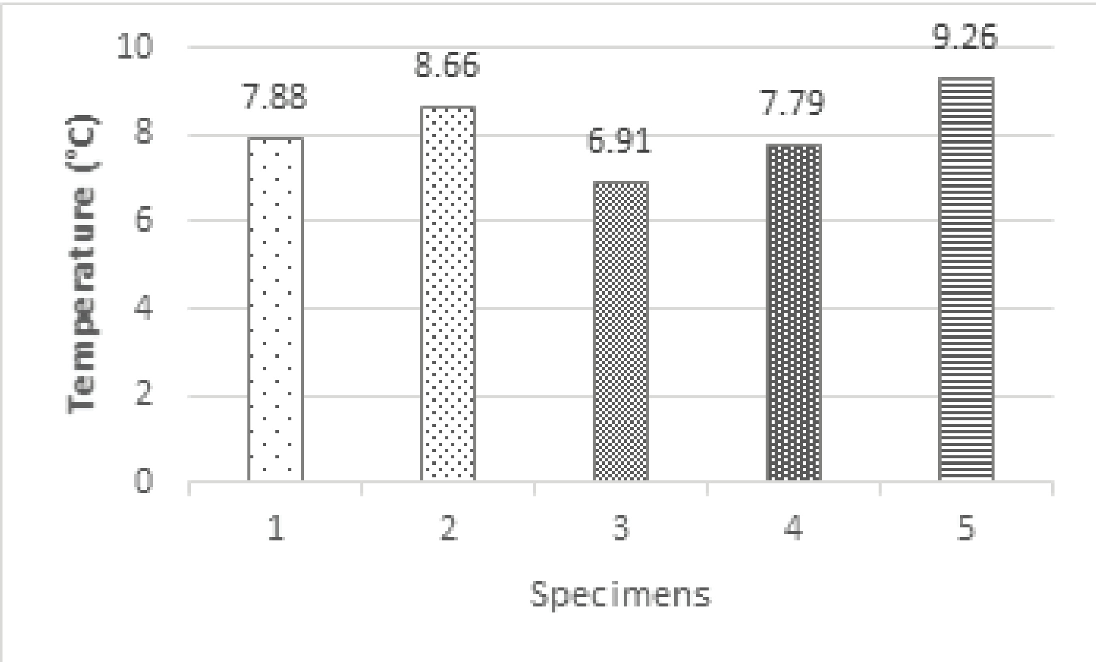


**Figure** 10: Comparison of the difference between the average of rate rise of OST and IST.

than all specimens with bamboo woven, which was 4:12:00. Density factor and thickness play a significant role in the heat propagation process. It was indicated by bamboo mass in specimen 5. The cuticle was considered to affect heat delay. It was also indicated in time lag (Figure 9), that specimens with bamboo cuticle have a longer time lag value than specimens without bamboo cuticle. Similarly, if referring to Figure 10, specimens with cuticle have a higher heat rate regarding the difference between the average rate

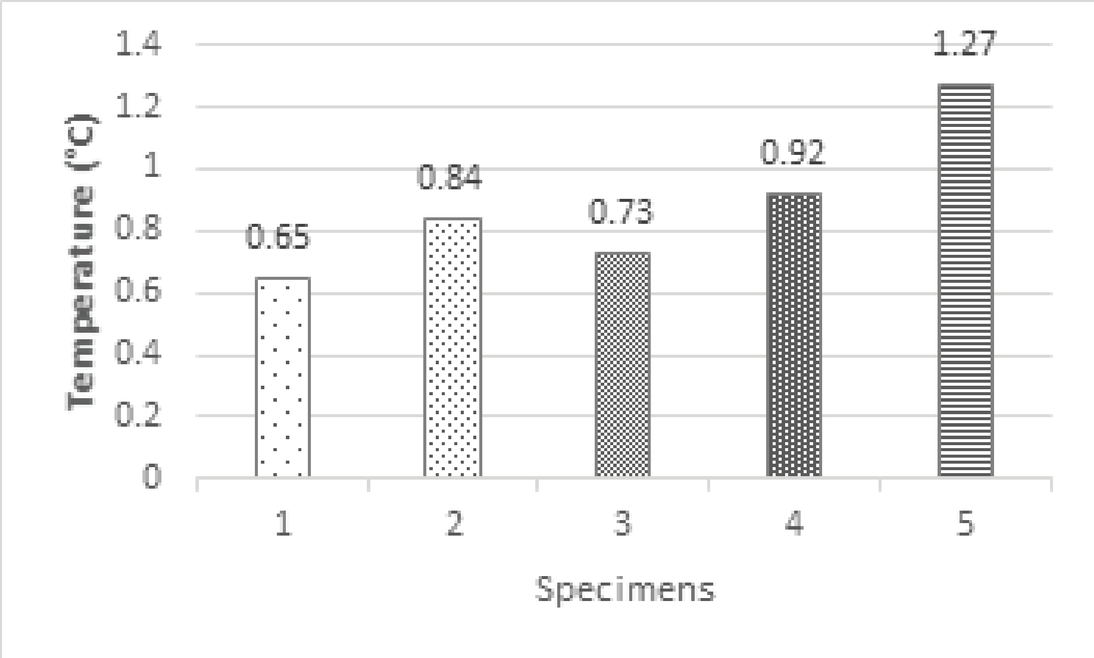


**Figure** 11: Comparison of the difference between the average of rate down of OST and IST.

rise of OST and IST. In contrast, specimens with cuticle have a lower heat rate regarding the difference between the average rate down of OST and IST (Figure 11).

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