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Thermal Insulation Properties of Organic and Inorganic Material in Clay Brick - A Review

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Abstract. Pore forming agent is widely used in clay brick making process whether originally organics or inorganics materials which can improve thermal insulation facing global warming issue. Many researchers triggered to discover the thermal insulation materials since the past decade due to responsibility to develop a comfort living demand for heating or cooling. This paper review on different types of thermal inorganic and organic insulation materials added into a clay brick to improve the thermal insulation properties. The scope of these reviews lies to the materials of; paper residue, rice husk, rice husk ash, olive stone flour, wheat straw, perlite, cigarette butt, vermiculite, waste marble powder and waste glass sludge. The discussions are made based on the properties of organic and inorganic materials used in improving the thermal insulation in clay brick. Hence, a throughout review of the composition and properties of brick and various factor related to manufacturing process is highly required for better standardization of clay bricks. A better understanding of different wastes incorporating clay brick utilize of various mining and industrial as well as achieving the goal of sustainable development.

Keywords: Organic Materials, Inorganic Materials, Thermal Insulation, Agriculture Waste

1. Introduction

The increment of population and migration of people to the urban area has automatically created a huge gap between demand and supply of affordable shelter. The difference between the demand and supply make the construction material price increase gradually with up to 60% of the total cost of building [1]. This is only focusing on construction materials itself without including the occupants' comfort demand. Building accounts for 40% of the global energy consumption and over 35% of the carbon dioxide emission, with a large fraction of energy consumption spent on maintain thermal comfort [2-5]. Heating and cooling system in a building becomes important as to increase occupants' comfort demands and the living standard.



Current buildings practices are too dependent on active systems without estimate the increase in the energy consumption of the building which also can lead to an increase in associated greenhouse gas emissions to ensure indoor thermal comfort. In achieving indoor thermal comfort condition of a building, passive method is the best solution to decrease usage of energy consumption and provide a healthy environment [6-10]. The passive method is very important for buildings in tropics which by using a mechanical system which is needed high energy consumption to condition the indoor environment for thermal comfort [8, 11].

However, most of the buildings are designated without considering the importance of passive methods for controlling the indoor environment and people are forced to depend on such systems with a consequence of ill health and productivity loss if failure to provide required thermal condition [11]. Therefore, thermal insulation performance can be improved by using insulation materials as a function of resistance to heat flow. The building that incorporates insulation materials usually has a low thermal conductivity of lower than 0.1 W/mK [12]. One of the most thermal insulation materials is the use of clay brick.

Nowadays, typical thermal insulation materials mainly include organic insulation materials and inorganic insulation materials in clay brick [27]. Therefore, this study focuses on the organic insulation materials such as rice husk ash, olive stone flour, wheat straw and rice husk while, inorganic insulation materials include perlite, cigarette butt, vermiculite, waste marble powder and waste glass sludge. This paper highlights the properties of organic and inorganic materials in clay brick to improve thermal insulation. Besides, other discussions on the thermal conductivity of a clay brick influenced by various factor were also conducted. In general, this paper provides fundamental knowledge on different types of insulation materials that can be used in clay brick and potentially provide the basis for a better choice of suitable, less energy consumption and sustainable thermal insulation materials for the construction industry.

2. Thermal Insulation Materials

The present literature review is focused on the most commonly used materials in a clay brick for thermal insulation. Therefore, it can be categorized and summarized as follows:

2.1 Inorganic Materials

Topçu (2007) [13] manufactured high heat conductivity resistant clay bricks containing perlite. Perlite was a vitreous substance with 2 - 6% water content. With addition up to 30% of perlite mixture thermal conductivity decrease from 0.407 W/mK to 0.215 W/mK at 950 °C firing temperature. If the additive up to 60% increased, the compressive strength decreased which not follow the standard.

Sarani (2013) [14] produced fired clay bricks incorporated with cigarette butts (CB) and the thermal conductivity was explained. Thermal conductivity coefficient of clay bricks incorporates cigarette butt decreased from 0.964 W/mK of control to 0.779 W/mK of 5% additive as increased the porosity. Sarani discovered the relationship between density and apparent porosity influenced the result of thermal conductivity. Sarani (2013) [15] on theoretical analysis of thermal conductivity of fired clay incorporated with CB with the same thermal coefficient as aforementioned. Sarani theorized dependence of thermal conductivity can be described by the significance of dry density. As the dry density decreased, the thermal conductivity also decreased and acts as an insulator.

Sutcu et al. (2015) [16] studied the influence of expanded vermiculite on physical properties and thermal conductivity of clay bricks. Vermiculite was quarry residue which is harmful to health if there is no proper management. Sutcu et al. reported the thermal conductivity of control brick was 0.96 W/mK while for the addition of 10 % vermiculite improved 30% in thermal conductivity with 0.65 W/mK, both fired at 900 °C. Again, Sutcu et al. mentioned the thermal conductivity increased as an additive increased influence with the particle size of an additive. Another studied has been investigated by the same author with different materials of waste marble powder incorporated in clay bricks. Sutcu et al. (2015) [17] reported thermal conductivity for both controls A1 fired at 950 °C was 0.973 W/mK. With addition up to 35% of waste marble, have decreased the thermal coefficient

conductivity of 0.401 W/mK. Compared to vermiculite, waste marble showed decreased in properties of thermal conductivity.

Meanwhile, there are different studied by Munir et al. (2018) [18]. The author studied the thermal properties of industrially manufactured clay bricks with the addition of WGS. WGS is a by-product of plate glass manufacturing. Clay bricks were produced with different proportion of WGS with 5 wt. %, 10 wt. %, 15 wt. %, 20 wt. % and 25 wt. %. The author investigated the thermal conductivity increase as adding the WGS while control brick specimens showed thermal conductivity is 0.53 W/mK reduced to 0.47 W/mK with 15% of WGS. It can be concluded that an increase in thermal insulation due to the attribution of reduced porosity of clay bricks after additional WGS. This is supported by Lianqian Mao (2018) [19]; the latter suggested that the addition waste glass could improve immobilization of heavy metals during the use of electroplating sludge in clay bricks production. The author then proved that the addition of waste glass can reduce the open porosity and surface area of bricks.

2.2 Organic Materials

The use of different types of organic material in clay can be led to improve thermal insulation. Sutcu and Akkurt (2009) [21] have studied paper residues can be used as a pore-forming agent in clay brick making process. The author reported that the production of porous and light-weight bricks with reduced thermal conductivity and acceptable compressive strength is accomplished. The author found that the thermal conductivity of the porous brick produced in this study (0.42 W/m K) showed more than 50% reduction compared to a local brick of the same composition (0.83 W/m K). A decrease in thermal conductivity will increase thermal insulation in clay bricks.

Görhan and Şimşek (2013) [22] studied the effect of rice husk additive on thermal and porosity while Eliche-Quesada et al. (2017) [23] focused on the characteristic of rice husk ash (RHA) and wood ash in sustainable clay matrix bricks. Görhan and Şimşek reported thermal coefficient conductivity of control clay brick was 0.45 W/mK when it was fired at 800 °C while the thermal coefficient decreased with 15% incorporated rice husk to 0.165 W/mK. Sutcu and Görhan discovered closely related between thermal conductivity with apparent porosity and densities. This study proved increased in firing temperature influenced an increased in thermal conductivity. Quesada et al. proved the additional of RHA up to 30 wt. % shown a small improvement in thermal conductivity of 0.68 W/mK compared to control brick of 1.05 W/mK. De Silva (2018) [24] also proved there is an only small improvement in clay brick that produced by RHA. At the peak temperature of the day, the internal temperature of clay brick incorporated with RHA showed 3 °C lower than conventional brick. As mentioned, thermal insulation is related to the total porosity of the clay bricks with different grain size. It shows that clay brick with rice husk has slightly improved in thermal insulation compared to RHA.

Nigay et al. (2017) [25] studied the combined experimental and theoretical study on a clay ceramic with the addition of organic additives (Olive Stone Flour) as round-shape particles of 55µm and Wheat Straw (WS) in fiber form of 877 µm particles size. The recent organic additives were mixed with 10 kg with 4wt% and 8wt% for OSF and WS then firing at 905 °C. The authors discussed the porosity of the clay contributes to thermal conductivity. There is 41% improvement of thermal conductivity of clay brick with an additional 8 wt. % of WS compare to control specimen of 0.46 W/mK from 0.80 W/mK. Meanwhile clay brick with 8 wt. % of OSF only showed a 23% decrease of thermal conductivity with 0.61 W/mK. This is proved that porosity is important in improving thermal conductivity.

3. Summary on Thermal Conductivity based on Different Compound Material in Clay Bricks

Comparison of the thermal conductivity coefficient of clay bricks containing organic and inorganic materials can be concluded in Table 1.

Table 1. The thermal conductivity and other related properties of clay brick with different compound material

Materials	Thermal conductivity coefficient, λ (W/mK)		Additive Ratio (%)	Firing Temperature (°C)	Performance Ratio (%)	Particle Size (μm)	References
	Control brick	Mixed composite					
Perlite	0.407	0.215	30	950	47	-	Topçu, 2007
Cigarette Butt (CB)	0.964	0.779	5	1050	19	-	Sarani, 2013
Vermiculite	0.96	0.650	10	900	30	-	Sutcu M., 2015
Waste Marble Powder	0.973	0.401	35	950	60	-	Sutcu M. et al., 2015
Waste Glass Sludge (WGS)	0.530	0.470	15	800	11	-	Munir M., (2018)
Paper residue	0.830	0.420	30	1100	49	-	Sutcu, 2009
Rice husk	0.450	0.173	15	800	61	-	Görhan, 2013
Rice husk ash (RHA)	1.050	0.700	30	1000	33	-	Quesada, 2017
Olive stone flour (OSF)	0.800	0.610	8	950	23	55	Nigay et al., 2017
Wheat straw	0.800	0.460	8	950	50	887	

From Table 1, a study from Görhan (2013) shows that the rice husk performed better in terms of the thermal performance in a clay brick given the performance ratio for up to 61% with $\lambda = 0.173$ W/mK as compared to other compound materials. Nevertheless, having rice husk ash as the compound material in clay brick giving the performance ratio lessen compared to the raw rice husk (Quesada, 2017). On the other hand, perlite as the inorganic material also potentially performed as the thermal conductivity material to the clay brick giving the performance ratio at 47% much higher compared to the rice husk ash as the organic compound. The waste glass and cigarette butt give thermal performance ratio in between 10 to 20% increment. It does give a slight improvement to the thermal performance when compared with the control clay brick; however, its utilization needs to be supported by their safety used due to the inorganic material nature that may cause some hazards if not being taken care properly.

4. Conclusion

Based on the literature reviews of the thermal insulation of clay brick containing inorganic and organic materials, the highest thermal performance is 61% of rice husk with an addition of 15% of additive that improves the thermal conductivity to 0.173 W/mK from 0.450 W/mK. Particle shape of additives affects the thermal conductivity of clay brick which can contribute huge impact of enhancement of air in the direction of the thermal gradient of the wall and the behaviour of the porosity. Firing temperature and additive ratio also give an impact to the thermal conductivity of clay bricks. Hence, the following conclusion can be drawn; the porosity and thermal conductivity are related to each other. Increased in porosity will lessen the thermal conductivity. Both organic and inorganic compounds potentially improved the thermal properties of clay brick. Having said that, organic material offered

better performance and safety used compared to the inorganic material. However, the inorganic compound can still be preferable considering improved material properties, processing and hazard free.

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