Thermal Insulation Properties of Insulated Concrete

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In building development, concrete is world most reliable, durable and versatile in construction materials. However, the heating and cooling system of the building is influenced by outside temperature due to extreme weather or areas condition leads to the consumption of a lot of electrical power. Thermally insulated concretes represent alternative construction materials to improve the thermal efficiency in building development. Various construction materials have different thermal insulation properties and thus, their suitability for various conditions vary. Thermal insulation properties are generally identified through specific heat, thermal conductivity, thermal diffusivity, thermal expansion, and mass loss. This paper present review the thermal insulation properties of variations insulated concrete are presently in growing demand of researchers to comfort and resolve prescribed issues related to insulated concrete in enhancing thermal insulation properties as a passive energy saving building.

Keywords: concrete, thermal conductivity, thermal diffusivity, specific heat, insulated concrete

Concrete is the most widely used construction materials throughout the world made up mixture of binder (such as cement, lime, mud etc.), coarse aggregate, fine aggregate and binding material with water [1, 2]. Next to water, concrete is the second most consumed substances on earth. Concrete is great referring to its capability toward endure high temperatures and fires, due to its high specific heat and low thermal conductivity [1-4]. Despite concrete is for the most part thought to have great fire resistance [5-7], concrete does need one improvement in cooling and heating system of buildings in hash condition which also major contributors to energy consumption worldwide [8-19]. A more challenging factor related to the sustainability of this industry is its considerable energy consumption [20, 21].

In 2009, around 43% of electricity consumption is attributed to the industrial sector of the total energy consumed in Malaysia. Electricity energy sector mainly used were gas and electricity in Malaysia is forecasted growth, the demand for electricity is expected to increase from 91,539 GWh in year 2007 to 108,732 GWh in year 2011 [22-25]. Figure 1 shows the primary energy consumption of Malaysia during 1980-2012 [26-29]. Major contributors to energy consumption in Malaysia and worldwide can be reduce by effective energy saving methods in buildings with a combination of building design and thermal insulation properties. Since the final energy demand in Malaysia is estimated reach at 116 Mtoe based on an annual growth rate of 8.1% in 2020 [30], new development of building materials perhaps can reduce the usage of electricity via air condition.

The energy consumption of building is decreased with the heat of loss which also reduces the cost of cooling and heating. Therefore, improvements in thermal insulation also affect sustainability of the concrete with the minimum use of energy, Modern construction and building industry have concern and target to offering high thermal insulation concrete as energy-efficiency of buildings in service. The insulated concrete development is used to reduce the heat losses or gain through the building envelope, and also materials with high thermal inertia that can store heat and delay the conduction of heat through structural elements

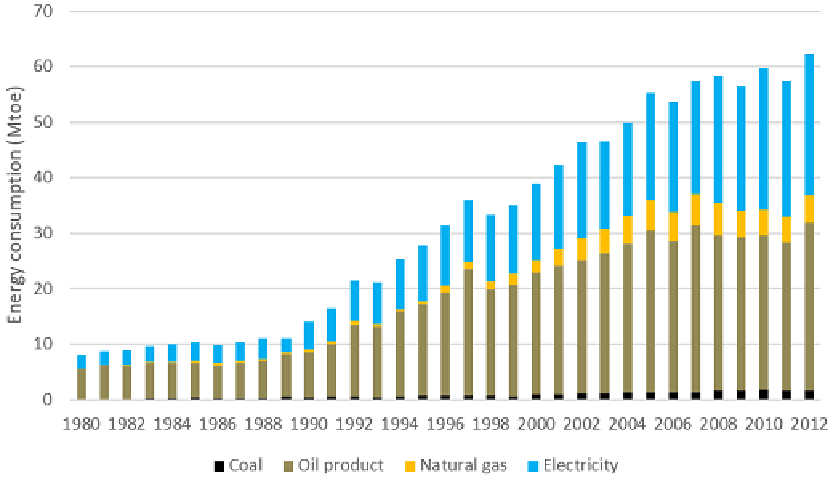

Fig. 1. Primary energy consumption of Malaysia during 1980-2012 [27-30]

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[31, 32]. The thermal insulation properties such as thermal conductivity, thermal diffusivity and specific heat has influenced by the temperature rise and materials in a concrete [33-38].

Experimental part

Measurement method of thermal insulation properties

Throughout the past decades, thermal insulation methods technology has been enhanced both in measurement methods for better understanding of the principles of heat flow through insulating materials. The property of insulation materials is most important property as considering thermal performance and energy conservation measures. The thermal conductivity (k-value, W/mK) is define as the time rate of steady state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area based on ASTM standards C168-97 [31]. Thermal insulation methods are commonly categorized as steady state methods and transient methods. Steady-state methods are principally suitable for analyzing materials with low or average thermal conductivities at moderate temperatures, where the transient methods measure the temperature–time response of the sample when a signal is sent out to create heat in the body [39, 40].

Steady-state methods

Steady-state methods is the method for determining thermal conductivity by controlling the heat of one-dimensional flow from one side to the other side based on the temperature rise over a known thickness of a sample [41]. The guarded hot plate is the most commonly used methods for measuring the thermal conductivity of materials type for instance insulation materials and homogenous composites [42]. This method required large sample (flat or cylinder) and higher temperature (180- 1000 °C) and needs a long time to set up a steady state temperature gradient to obtain thermal conductivity result (0.0001 to 2 W/mK) [42-44]. Previously, the measurement of the thermal conductivity values of some of the building materials at mean temperature has used guarded hot plate [45-47].

The equipment of guarded hot plate consists of isolated guard area separated by a small coplanar gap and heaters in a central metered section (Figure 2) [48]. The heater or temperature sensor is placed in the guard sections and central in all surfaces at right positions. While the hot plate is applied by measured dc-power and the guard sections and cold plate are carefully modified to the various temperature and controlled in order to ensure the uniform temperatures at the specimen surfaces. Thermal conductivity is obtained by setting the zero temperature difference through the gap and required temperature difference across the specimen pieces.

Transient methods

The thermal constants analyzer consists of a variety of transient plane source probes connected to a computerized control unit measure a response as a signal is sent out to create heat in the sample. The short time (100 - 120 s) mainly distinguish by these method with measurement temperature is -100 to 1000°C required to obtain wide range of thermal conductivity the needed results (0.016 to 6 W/mK) thus suitable for huge range of different materials [40, 49, 50]. The transient (dynamic) methods can be used to determine thermal properties such as thermal conductivity and thermal diffusivity of good-conducting solid materials or both, for broader range of temperatures [40]. Conveniently, transient methods have hot wire technique use for measuring the thermal conductivity of polymers and liquids or solid non-electrically conducting materials. The latest development method is the transient plane source (TPS) technique.

The sensor of this method is sandwiched between two halves of the sample material to be tested as shows in the Figure 3. The sensor of TPS method is covered by a polymer coating allows measurements of electrically conducting materials. The sample needs to be smooth inn surface for this test method. Then a constant temperature difference is built up the thin interface (gas or vacuum) caused by thermal contact resistance between the sensor surface and the sample surface. Thus the constant temperature will not affect the results which give advantages in a transient method compared to steady state methods. Previous study has been used this method to study the thermal conductivity, diffusivity and heat capacity of building materials (wood concrete mixtures) at room temperature [49].

Thermal insulation properties

Thermal insulation properties of concrete are relevant towards concrete use, especially when it related to structures where it is desirable to have low thermal conductivity and thermal diffusivity, high specific heat and capability of heat losses or gain through the building envelope when expose in harsh condition. The differences in thermal insulation properties included the specific heat, thermal conductivity and thermal diffusivity in concrete arise from differences in insulated materials used, density, temperature and moisture content of concretes [45-52].

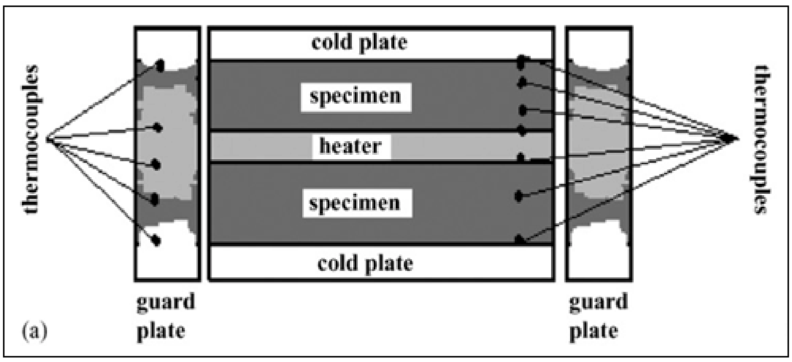

Fig. 2. Steady-state measurement methods by guarded hot-plate [48]

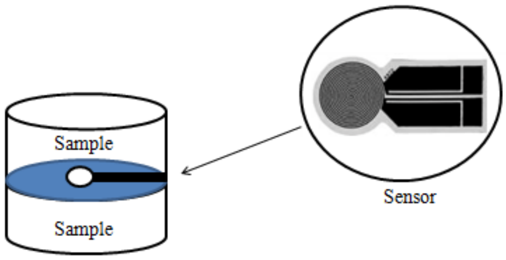

Fig. 3. Schematic diagram of TPS methods

Specific heat

Most of the thermal insulation properties carried out the specific heat basically by measured the amount of heat per unit mass required to change the temperature of a material by one degree (1°). Specific heat is highly influenced by temperature, density of concrete, aggregate type, and moisture content [53-55]. Values of the specific heat concrete and masonry materials vary between 0.79 and 0.92 kJ/m³K [56] from previous studied. Besides that, the specific heat of normal strength concrete was measured at the ages from 1 day to 7 days by previous research varied from 1.122 to 0.888 (MJ/m³K) respectively which the specific heat was decreasing due to increasing aging days [57]. Some heat-capacity storage is present in all buildings in the floors, furnishings, gypsum board and framing. Most of materials used for as thermal storage required high specific heat value [50]. However, the specific heat gave the different results when tested to the temperature is rise.

Several concrete has tested to the highest temperature to study on specific heat such as normal concrete [58], high strength concrete, and fly ash concrete [59] (Figure 4). Most of these type of concrete perform constant up to 300°C, and then increases between 650 °C and 800 °C indicates the specific heat has linear relationship with the temperature. However, the highest values of specific heat slightly shows as of fly ash concrete through the temperature compare to others type of concrete may influenced by permeability characteristics of fly ash concrete which are less permeable compare to the others concrete [55, 60, 61-65]. The decrease of specific heat values (700°C to 800°C) explains that beyond higher temperature the concrete itself decomposition from solid to liquid. Previous research revealed the physiochemical processes that occur in the cement paste and aggregate (above 600°C) has affected the measured result of the specific heat of concrete [59].

Thermal Conductivity

The thermal conductivity commonly conducted in order to study the of heat flow rate to the temperature gradient, and represents the uniform flow of heat through concrete of unit thickness over a unit area subjected to a unit temperature difference between the two opposite faces. For normal concrete range of thermal conductivity from 0.62 to 3.3 W/m/K across more than five folds of magnitude depending on the temperature, moisture condition and types of coarse aggregate [33, 57, 58]. Al-Hammad et al. [46] studied most suitable for insulation application in buildings in hot climates for the thermal conductivity of insulation materials is at a mean temperature of 35 °C. Besides, Bouguerra et al. [6] has also measured the thermal conductivity to study the highly heterogeneous and porous building materials (wood concrete mixtures) at room temperature. It was shown that the thermal conductivity decrease while the heat capacity increases with increasing volume fraction of wood aggregates.

Demirboga et al. [61] studied the effect of fly ash on the thermal conductivity of concrete. Class C fly ash was added as replacement for cement by decreasing the cement weights in the ratios of 15 % and 30% by weight (Figure 5). The highest thermal conductivity of 1.230 W/mK (Density: 2390 kg/m^3) was observed with control samples (plain concrete). It decreased with the increase of fly ash as replacement for cement for 15 % fly ash (Density: 2340 kg/m^3) at 1.083 and 30% of fly ash (Density: 2290 kg/m^3). Besides, the properties of aggregates such as pore structure, hardness, strength, specific gravity, roughness, and chemical and mineral composition also affected the thermal conductivity and density. Previous research has

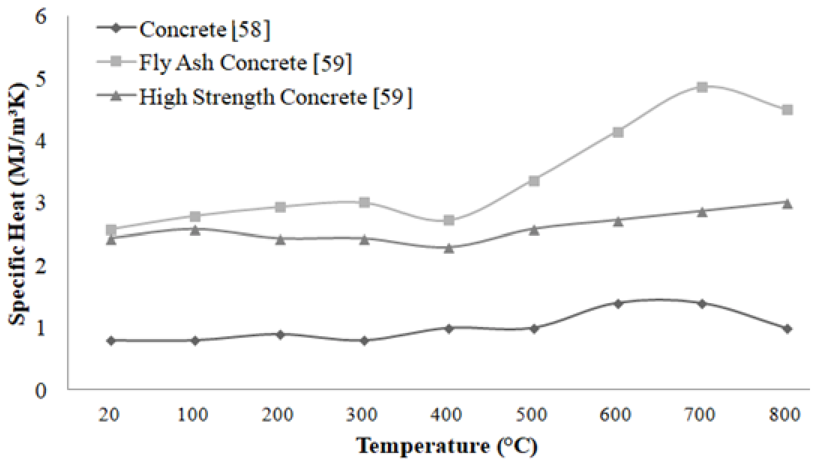

Fig. 4. Specific heat tested to the highest temperature of several concrete

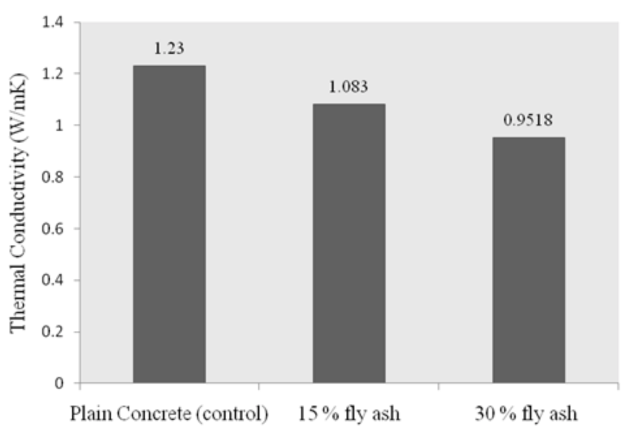

Fig. 5. The effects of fly ash (15% and 30% replacement of cement) on thermal conductivity [61]

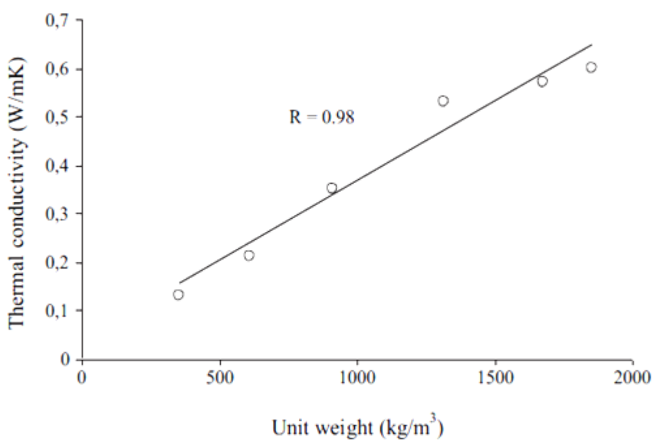

Fig. 6. Effect of unit weight on the thermal conductivity of concrete with the replacement of natural sand by expanded perlite [59]

studied the effect of expanded perlite in replacing the natural sand from 0% (normal concrete) to 100% with steps of 20% (Figure 6). Due to its low density (reduced to a minimum of 392 kg/m^3) with the present of the expanded perlite increase, the thermal conductivity also low (0.130 W/mK). The increase of porous structure in expanded perlite shows the low thermal conductivity and density where the pores reduce the heat conduct through the concrete.

Thermal diffusivity

Additionally to specific heat and thermal conductivity, thermal diffusivity is another property that is often used in passive solar design references. Thermal diffusivity is a measure of heat transport relative to energy storage. The effective thermal diffusivity of the materials perform well on heat transfer than heat storage while other studies on various type of concrete proved the reduced of thermal diffusivity will reduce thermal conductivity [58, 60, 63]. Liu et al. has shows the properties of thermal diffusivity on the variation percentage of expanded perlite aggregate replacing natural sand. Figure 7 described the relationship of thermal diffusivity and volumetric heat capacity. The thermal diffusivity reductions from 0.9977 to 0.3438 mm^2/s and volumetric heat capacity from 1.8354 to 1.105 MJ/m^{3}K were approximately with the addition of expanded perlite aggregate (0 to 100%). The decreasing thermal conductivity divided by the increasing volumetric heat capacity gave the decreasing trend of thermal diffusivity as shows in Formula 1. Thermal diffusivity is defined as the ratio of thermal conductivity to volumetric heat capacity:

$$\alpha = \frac{k}{\rho C} \quad (1)$$

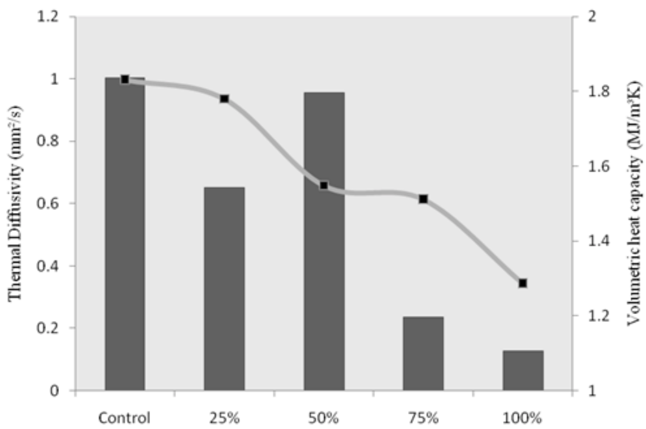

Fig. 7. Effect of density on the thermal diffusivity of concrete with the replacement of natural sand by expanded perlite [63]

Conclusions

The insulation properties of insulated concretes have been review through the method measurement used (steady-state and transient methods) and thermal insulation properties such as specific heat, thermal conductivity and thermal diffusivity. The improvement of normal concrete toward insulated concrete show significant potential as a viable material for energy-efficiency of buildings in service. From the review, the specific heat has shows the decreasing due to the aging time, affected by the materials used in the building and also obtained different results were found when temperature rise. The thermal conductivity depends on materials type of aggregate, moisture condition, temperature and also affected by density of the concrete. The thermal diffusivity clarified reduced of thermal conductivity will reduce the thermal diffusivity and also related to the formula which influence by volumetric heat capacity. Several improvements remain to be studied and applied to enhance the thermal insulation properties of concrete performance.

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