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Simplified Explicit Model to Measure Transient Heat Transfer in Foamcrete Panel System

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Abstract: The complexity of calculating transient heat transfer in foamcrete panel is complex due to its porous and multi-phase material nature which can require the numerical solution of two or three-dimensional transient conduction equations. This paper reports the basis of one-dimensional Finite Difference method to attain thermal properties of foamcrete. In addition, this paper also integrates the implementation of the method and the justification of thermal properties model of foamcrete. A one-dimensional finite difference heat conduction programme has been developed to predict the temperature growth through the thickness of the foamcrete panel, based on preliminary estimation of the thermal conductivity-temperature relationship as a function of porosity and radiation within the voids. The precision of the model was then assessed by comparing predicted and experimental temperature profiles acquired from small scale heat transfer test on foamcrete panel, so that the temperature history of the specimen calculated by the programme closely matches those recorded during the experiment.

Key words: lightweight concrete, foamcrete, foamed concrete, thermal analysis, thermal properties, heat transfer, fire

INTRODUCTION

With rapid development in computer and software engineering and technology, numerous designers and building product developers look towards computer aided modelling as an economic means to supplement fire resistance testing as a method of performance verification. According to heat flow anaylsis studies and structural verification analysis, and on the knowledge of the behaviour of materials at high temperatures and fire condition, the computer-generated approach may offer the engineer and designer with a solution of substantial practical value. The expansion of computational techniques in fire safety engineering has formerly been rather ignored, but the general level of consciousness in the area of numerical modelling is mounting. Rising demand has emerged for enhanced predictive methods based on refined analysis to establish the fire resistance of the building components. At this time, non-linear structural analysis techniques are progressively allowing designers to envisage the structural performance under a given set of time-varying temperature. This effort has enabled the most responsive members to be identified. Nevertheless, if the design is not to be over conservative, it is essential to be able to predict the temperature distribution in all structural members with a realistic precision. The major part of the current information on the performance of passive fire protection materials and systems has been derived from standard fire tests.

Faced with this situation, there has been ongoing research with the aim of analyzing the behaviour of elements of building material in fire by studying their fire resistance in the standard furnace tests and developing sufficient techniques for interpolation and extrapolation. As understanding increases, a natural progression is the expansion of analytical procedures for the best possible design of building material elements to offer a specified fire resistance. At present, researches on building material heat transfer and fire analysis have become progressively more significant. According to the current design codes, the fire resistance of building materials are traditionally determined either by assessing the capability of load-bearing capacity or by evaluating fire resistance rating times through empirical relations. Practical and precise temperature formulations for material and structural members subjected to fire conditions are of paramount significance for researches in structural fire engineering.

At this time, the problem of a porous medium like foamcrete exposed to elevated temperature is of great attention in civil engineering. Foamcrete can be defined as a cementitious material having a minimum of 20 per cent by volume of mechanically entrained foam in the mortar slurry in which air-pores are entrapped in the matrix by means of a suitable foaming agent. The air-pores are initiated by agitating air with a foaming agent diluted with water; the foam then carefully mixes together with the cement slurry to form foamcrete. Integrating the air-pores into the base matrix gives a low self-weight, high workability, excellent insulating values, but lower strength in contrast to normal strength concrete. During disclosure to elevated temperatures, many non-linear phenomenons' concerning the different phases constituting the porous media in foamcrete should be taken into account It should be pointed out that not only heat conduction and vapour diffusion must be considered, but also liquid water flow due to pressure gradients and capillary effects caused by interface curvature inside pores

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produced by surface tension that alters the equilibrium between liquid water and gas. In order to consider fire resistance of any material, it is crucial to distinguish temperature history of the material in fire conditions. Although similar principles of heat transfer govern the temperature development throughout material, different analytical or numerical methods may be realistic to attain the solution. In sequence to get thermal properties of foamcrete, a one-dimensional heat transfer model is adequate and Finite Difference Method (FDM) emerges to be the simplest method to be executed.

This paper focuses on the development of one-dimensional Finite Difference model which can be employed to resolve transient heat conduction problems in multi-layer panels. The convection and radiation boundary conditions on both fire exposed side and unexposed side of the material are also considered. In addition, thermal property models and their validation using the experimental results will also be presented. The next section will depict the basis of the modelling method which includes the development of one-dimensional Finite Difference formulation which can be employed to solve transient heat conduction problems for porous material like foamcrete.

Empirical and Theoretical Model:

The mathematical model used in the analysis considers foamcrete as a multiphase porous material. The transient heat transfer through foamcrete is modelled using one-dimensional Finite Difference formulation. A computer program to model the transient heat transfer through foamcrete has been developed and implemented in the familiar environment of Microsoft Excel using VBA based on one-dimensional Finite Difference formulations. The modelling procedure has been systematically validated by comparisons with a number of analytical solutions and simulation results using ABAQUS/Standard. The general three-dimensional transient heat-conduction equation (based on Fourier's law of conduction) in Cartesian coordinates is (Holman, 2002):

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) \tag{1}$$

where

$T(x,y,z,t)$ is temperature (˚C);
$k(T)$ is temperature dependent thermal conductivity (W/mK);
ρ is material density (kg/m^3);
c is specific heat of material (J/kg°C);
t is time (sec);
x, y, z are Cartesian coordinates.

The right hand side of Eq. (1) stand for the net heat conduction in a solid material, whereas the left hand side represents the accumulated internal energy.

Calculation of heat flow in solids is based on the solution of this differential equation. Due to complexity of many geometric shapes and boundary conditions of practical interest, analytical solutions to Eq. (1) are not always possible. Finite Difference Method is a relatively simple technique which can provide approximate numerical solutions to many practical cases. FDM replaces derivative expressions in Eq. (1) with approximately equivalent partial difference quotients. Two approaches can be taken to transform the partial differential equation into finite difference equation; mathematical replacement approach and physical heat balance approach. The two techniques often result in the same finite difference equations. However, the heat balance technique might suit better to irregular boundaries with convective heat loss (Croft and Lilley, 1977) and therefore is adopted in this study. The consequential finite difference equations can be either explicit or implicit. In the implicit approach a set of simultaneous equations has to be solved at each step in time. Although the solution process is relatively complex, it allows for the use of larger time intervals. In the explicit approach, on the other hand, the temperature of a volume cell at a time step is computed directly based on the temperatures of the adjacent cells in the last time step, leading to a very simple scheme of computation (Croft and Lilley, 1977). Given the simplicity and effectiveness the explicit approach in finite difference method provides, it was found suitable for the purpose of this study. Although time intervals required in this method are small, it does not cause any further complications to the computations, since small time steps are already necessary in fire resistance analysis due to rapid changes of temperature in fire conditions. If the thickness of the foamcrete panel is small in comparison to the other dimensions, the problem will reduce to a one dimensional heat transfer analysis, i.e. the heat flow is perpendicular to the face except near the edges. Hence, the governing Eq. (1) with no heat generation reduces to:

$$\rho c \frac{\partial T(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(k(T) \frac{\partial T(x,t)}{\partial x} \right) \tag{2}$$

where $0 \le x \le L$, for $t > 0$, L is the thickness of the panel

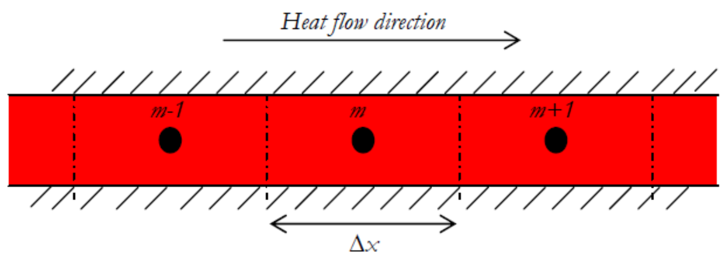

Fig. 1: Finite Difference discretization for node *m* within the material

Assuming a homogeneous material and choosing the explicit method, the temperature of a volume cell (Fig. 1 and Fig. 2) at a time step is computed directly based on the temperatures of the adjacent cells in the last time step which leads to a very straightforward scheme of computation (Wang, 1995):

(i) For a typical node *m* within the material (Fig. 1):

$$T'_m = F_0 [\frac{2(k_{m-1,m} T_{m-1} + k_{m+1,m} T_{m+1})}{k_{m-1,m} + k_{m+1,m}} + T_m (\frac{1}{F_0} - 2)] \tag{3}$$

where F_0 is defined as:

$$F_0 = \frac{(k_{m-1,m} + k_{m+1,m})\Delta t}{2\rho c (\Delta x)^2} \tag{4}$$

T'_m is the temperature of *m* in the subsequent time step and $k_{i,j}$ is the thermal conductivity at the average temperature of cells *i* and *j*:

$$k_{i,j} = k(\frac{T_i + T_j}{2}) \tag{5}$$

Numerical stability under the explicit scheme requires:

$$\Delta t \le \frac{\rho c (\Delta x)^2}{(k_{m-1,m} + k_{m+1,m})} \tag{6}$$

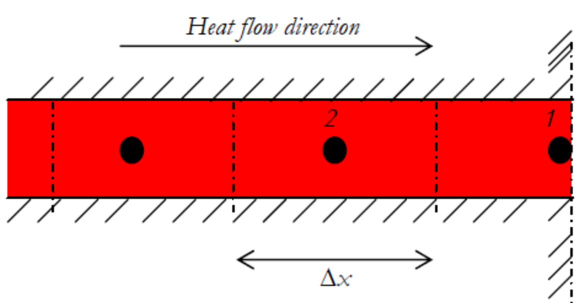

Fig. 2: Finite Difference discretization for boundary node

(ii) For a boundary node, when subjected to convective and radiative boundary conditions (Fig. 2):

$$T_1^{'} = 2F_0[T_2 + \frac{h\Delta x}{k_1}T_\infty + (\frac{1}{2F_0} - 1 - \frac{h\Delta x}{k_1})T_1) + \phi e\sigma[(T_\infty + 273)^4 - (T_1 + 273)^4]\frac{2\Delta t}{\rho c\Delta x} \quad (7)$$

where F_0 is $F_0 = \dfrac{k_1\Delta t}{\rho c(\Delta x)^2}$

$h(T)$ is convection heat transfer coefficient (W/m^{2}K);
T_∞ is the ambient temperature (°C);
ϕ is a geometric "view factor"
e is the effective emissivity
σ is Stefan-Boltzmann constant (5.67 x 10^{-8} W/m^2.K^4).

Numerical stability limits the time step to:

$$\Delta t \le \frac{0.5\rho c(\Delta x)^2}{k_1}[1 + \frac{h\Delta x}{k_1} + \frac{\phi E\sigma\Delta x}{k_1}\cdot\frac{(T_1 + 273)^4}{T_1}]^{-1} \quad (8)$$

It should be pointed out that foamcrete panel is recognized to have a uniform initial temperature equal to the ambient temperature. On the unexposed boundary, the convective heat transfer coefficient (*h*) is assumed to be constant and the value is taken as 10 W/m^{2}K (Othuman Mydin and Wang, 2011). The emissivity of the surface depends on the material. For concrete, the surface emissivity will be taken as 0.92 (Ozisik, 1985). The exposed boundary conditions are the recorded temperatures on the exposed surface of fire test specimens.

Thermal Properties Of Foamcrete At Elevated Temperatures:

Foamcrete is a composite material made from a combination of sand, cement binder and water. After mixing, the cement hydrates and hardens into a stone like material. In theory, the combination of mass and heat transfer should be carried out to obtain temperatures in foamcrete construction. However, modelling mass transfer is complex. A common approximation is to conduct heat transfer only, but modifying the material thermal properties to reflect the effects of water movement. In order to utilize the proposed numerical method for heat transfer analysis, data on density, specific heat and thermal conductivity should be provided. This section will only present summary of these data which were based on comprehensive experimental investigation on thermal properties of foamcrete (density of 650kg/m^3) conducted by the author (Othuman Mydin and Wang, 2011).

Foamcrete Dry Density:

Moisture flow in foamcrete can be expressed in two different ways; either in terms of the evaporable or free water. Evaporation of free and of some of the chemically bonded water will cause dehydration in foamcrete, which will influence all the abovementioned three items of thermal properties. The dehydration process starts as early as 90°C (Othuman Mydin and Wang, 2011). Fig. 3 shows recorded density of foamcrete at different temperatures, as ratio of the original density for initial density values of 650 kg/m^3.

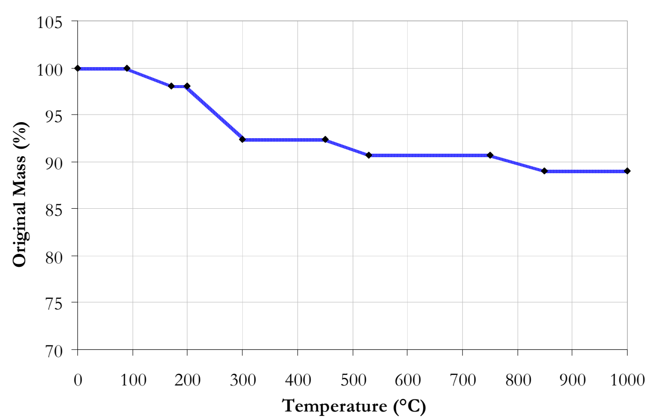

Fig. 3: Density of foamcrete as a function of temperature (% of the original density)

Foamcrete Specific Heat:

In terms of specific heat of foamcrete, it can be divided into two parts; the base value corresponding to a mixture of the dry components and the effect of water evaporation. The temperature-dependent specific heat of foamcrete experience one peak corresponding to the dehydration reaction of foamcrete between 90°C to 170°C as shown in Fig. 4. This peak represents the energy consumed to dissociate and evaporate water and include the effect of water movement and recondensation of water in cooler regions of foamcrete.

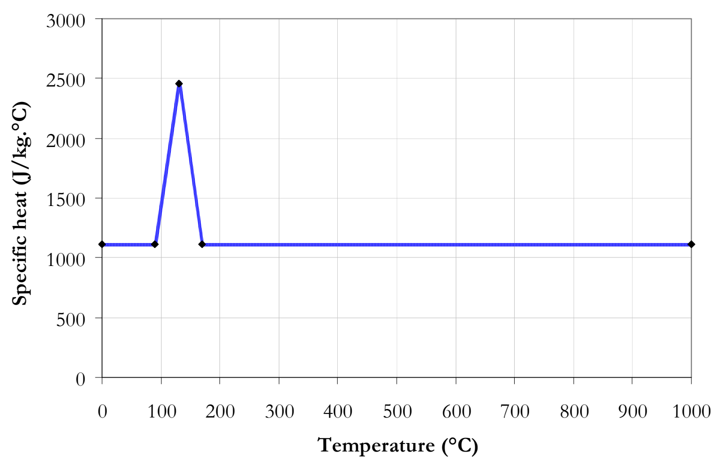

Fig. 4: Specific heat of foamcrete as a function of temperature

The calculated base value of specific heat at ambient temperature for 650 kg/m^3 density was 1110 J/kg°C (Othuman Mydin and Wang, 2011) and the additional specific heat at the dehydration reaction can be expressed by:

$$\Delta c = \frac{2.26 \times 10^6}{\Delta T} \times e_w \times f \,(J/kg°C) \tag{9}$$

in which the value of 2.26 x 10^6 J/kg is the latent heat of evaporation of water, Δc is the average additional specific heat, e is dehydration water content (percentage by total weight), ΔT is the magnitude of the temperature interval during which water is evaporated and f is a modification factor accounting for water movement. A value of f =1.4 was used for standard fire conditions. Fig. 4 shows the temperature-dependent specific heat of 650 kg/m^3 density.

Foamcrete Thermal Conductivity:

The thermal conductivity is the key parameter for evaluating the performance of foamcrete based system. Rather than using the simplest parallel and serial models, a model employing a theory closer to reality has been introduced into this study. Given that foamcrete is a porous material, heat transfer through this material is a combination of all three modes: conduction through the solid and convection and radiation through the pores. Therefore the effective thermal conductivity of foamcrete should include these effects. If the macroscopic scale is much larger than the randomly distributed individual pores and the pores are of the same size and uniformly distributed, it is possible to develop an analytical method to calculate the overall thermal conductivity of the coating. This effective thermal conductivity can be affected by many factors such as temperature, density, moisture content and porosity of the material. Assuming foamcrete is made of solid substrate and uniformly distributed spherical pores, the effective thermal conductivity of foamcrete may be calculated using the following equation (Yuan, 2009):

$$k^* = k_s \frac{k_g \varepsilon^{\frac{2}{3}} + (1 - \varepsilon^{\frac{2}{3}})k_s}{k_g(\varepsilon^{\frac{2}{3}} - \varepsilon) + (1 - \varepsilon^{\frac{2}{3}} + \varepsilon)k_s} \tag{10}$$

where k^* is the effective thermal conductivity of foamcrete, k_g is effective thermal conductivity of gas to account for heat transfer in the pores, k_s is the thermal conductivity of the solid and ε is the porosity of the material (the ratio of the volume of void pore to the overall volume). In this study, the thermal conductivity of solid dried foamcrete (k_s) is 0.5 W/m.°C and the porosity of 650 kg/m^3 density is 75% (Othuman Mydin and Wang, 2011).

Foamcrete Thermal Conductivity Of The Gas Inclusion:

The heat transfer through the pores of a porous material should normally include all mechanisms of heat transfer: conduction, radiation and convection. However, since the pores in an intumescent coating normally range from several hundred microns to less than 5 mm, natural convection within the pores is small and can be neglected. In studies of porous materials, the radiative component of heat transfer has often been neglected because these studies deal with heat transfer at ambient temperature or low temperatures. However, for fire applications where the temperatures are high, accurate calculation of heat transfer within the pores should also incorporate radiative heat transfer. Thus for this study, the equivalent thermal conductivity of the gas will consist of contributions from pure conduction (conductance through gas) and radiation.

Foamcrete Conductance Through Gas Phase:

The available experimental data shows that the conductance related thermal conductivity of gas typically has strong temperature and pressure dependencies (Smith, 1981). Under atmospheric pressure, the gas thermal conductivity as a function of temperature:

$$\lambda_{cond} = \lambda_{g0}\left(\frac{T}{T_0}\right)^{0.8} \tag{11}$$

where λ_{g0}=0.0246W/mK, is thermal conductivity of gas at temperature T_0=273K (0°C).

A similar formulation has been given more recently by Di Blasi (2000). The thermal conductivity of gas, regardless its nature, is expressed as:

$$\lambda_{cond} = 4.815\times10^{-4} T^{0.717} W/m\cdot K \tag{12}$$

Figure 5 compares these two models of calculating conductance related thermal conductivity of gas. The results show that the two models produce very close values over a wide range of temperatures from 273K (0℃) to 1273K (1000℃). In this study, the Di Blasi’s model has been selected for calculation (Di Blasi, 2000).

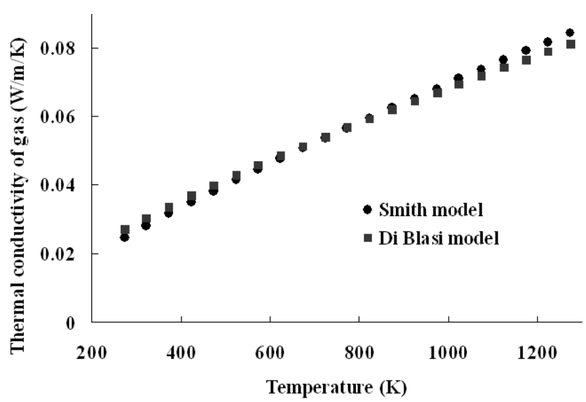

Fig. 5: Two different models of relationship between conductance related gas thermal conductivity and temperature

Radiation Through Gas:

As temperature increases, thermal radiation becomes important and cannot be neglected in porous materials. The effect of thermal radiation across pores was discussed by Loeb (1954), who has been accredited for the following equation to calculate the contribution of thermal radiation to the overall thermal conductivity of a pore:

$$\lambda_{rad} = 4Gde\sigma T^3 \tag{13}$$

where G value is the average width of the pore divided by the maximum width of the pore and both quantities should be determined in the direction of the thermal gradient. Therefore, G is 1 for laminar pores and cylindrical pores with axes parallel to the heat flow direction, G is π/4 for cylindrical pores with axes perpendicular to the heat flow direction. For spherical pores, G = 2/3.

Due to the difficulty in accessing the original article by Loeb (1954), the following will present a derivation of Eq. (13). Refer to Figure 6 which shows a spherical pore.

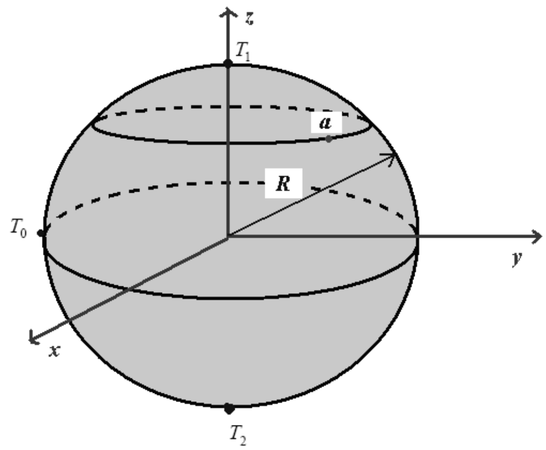

Fig. 6: Illustration of a general spherical pore for calculation of radiation

For a surface element on the solid-pore boundary at *a*, the net value of normal component of radiation Q_a is equal to the difference between the heat flux leaving and the energy coming to the surface:

$$Q_a^r = e\sigma T_a^4 - e\sigma \int_{A'} T_{a'}^4 dF_{dA-dA'} \tag{14}$$

where *a'* is any other emitting element on the surface of this spherical pore; *A* and *A'* represent allocated area for *a* and *a'*, respectively; $dF_{dA-dA'}$ is view factor, and for a spherical enclosure it is obtained from simple geometric consideration as:

$$dF_{dA-dA'} = \frac{dA'}{4\pi R^2} \tag{15}$$

Thus, in this case, the second term on the right hand side of Eq. (14) becomes constant:

$$Q_a^r = e\sigma \left(T_a^4 - \frac{1}{4\pi R^2} \int_{A'} T_{a'}^4 dA' \right) \tag{16}$$

From simple consideration, the mean temperature is:

$$T_0 = \frac{T_1 + T_2}{2} = \frac{1}{4\pi R^2} \int_{A'} T_{a'} dA' \tag{17}$$

Therefore the normal component of radiation becomes:

$$Q_a^r = e\sigma \left(T_a^4 - T_0^4 \right) \tag{18}$$

Assuming $T_a \approx T_0$, then:

$$Q_a^r = 4e\sigma T_0^3 \Delta T \tag{19}$$

where $\Delta T = T_a - T_0$

At the top point of this spherical pore, it has:

$$Q_1 = 4e\sigma T_0^3 (T_1 - T_0) \tag{20}$$

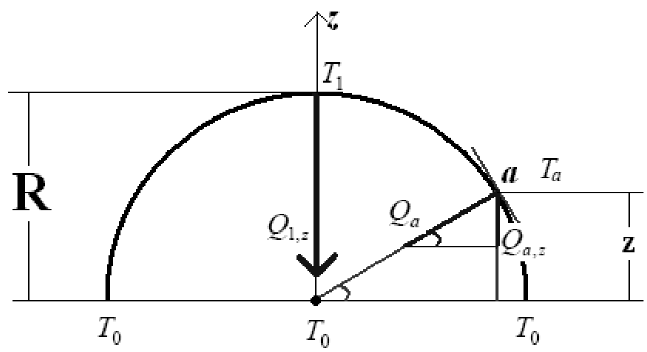

Fig. 7: Calculation of radiation along heat flow direction

As demonstrated in Figure 7, heat flow is along the z axis, therefore only the z direction component of heat flux from every point "*a*" is considered to make contribution to radiation through the whole pore.

Because thermal gradient is linear along z direction, then:

$$T_a - T_0 = \frac{Z}{R}(T_1 - T_0) \Rightarrow Q_a = \frac{Z}{R} Q_1 \tag{21}$$

Where Z is coordinate of point *a* along *z* axis (central point of sphere is "0")

The *z* component of radiation at point *a* is:

$$Q_{a,z} = \frac{Z}{R} Q_a \tag{22}$$

By simple calculation, the *z* direction component of heat flux from point "*a*" is described as:

$$Q_{a,z} = Q_1 \times \frac{Z^2}{R^2} \tag{23}$$

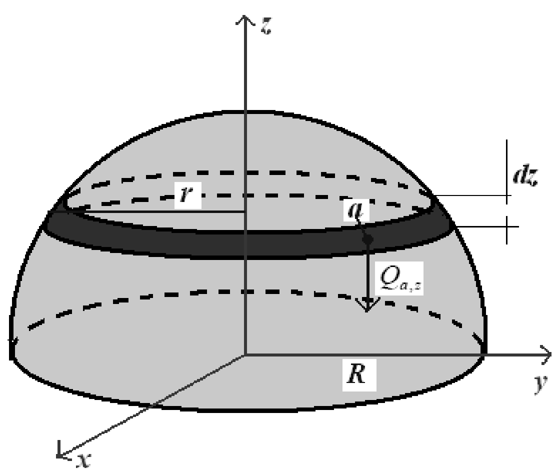

Fig. 8: Calculation of total amount of radiation for a hemisphere

Refer to Figure 8, a ring strip is on the surface of hemisphere, with an infinitesimal height *dZ*. For a spherical surface, it can be proved that every ring strip that has the same height provides the same surface area. Therefore, for every single infinitesimal ring in Figure 8, the surface area can be expressed as:

$$S_{ring} = 2\pi R dZ \tag{24}$$

Heat responsible for z direction radiation is therefore calculated, for this ring surface:

$$H_z = Q_1 \frac{Z^2}{R^2} \times 2\pi R dZ \tag{25}$$

The total amount of *z* direction radiation of this hemisphere is obtained by integration:

$$H_{half} = \int_0^R Q_1 \frac{Z^2}{R^2} \times 2\pi R dZ = Q_1 \frac{2\pi}{R} \int_0^R Z^2 dZ = \frac{2\pi R^2}{3} Q_1 \tag{26}$$

In a simple way, the lower half of sphere provides the same effect as the upper half, so the total amount of heat transferred by radiation is:

$$H_{whole} = 2H_{half} = \frac{4\pi R^2}{3} Q_1 \tag{27}$$

The equivalent heat flux along the *z* direction over the projected area is:

$$Q_{eq} = \frac{H_{whole}}{\pi R^2} = \frac{4}{3} Q_1 \Rightarrow Q_{eq} = \frac{4}{3} \times 4e\sigma T_0^3 (T_1 - T_0) \tag{28}$$

The thermal gradient in this case is $\frac{T_1 - T_2}{d}$, where $d = 2R$ is the diameter of sphere. Therefore, the effective thermal conductivity for radiation, within a sphere, is described as:

$$\lambda_{rad} = \frac{2}{3} \times 4de\sigma T^3 \tag{29}$$

Foamcrete Effective Thermal Conductivity:

Since the size of the pores is very small (never larger than 5mm), natural convection in the pores can be neglected (Yuan, 2009). Combining the contributions to heat transfer in a pore by pure conduction and radiation, the total thermal conductivity of the gas within the pore can be given as:

$$k_g = 4.815 \times 10^{-4} T^{0.717} + \frac{2}{3} \times 4d_e \sigma T^3 \tag{30}$$

where *T* is absolute temperature and d_e is the effective diameter of the pores. In this study d_e =0.72mm for 650 kg/m^3 density (Othuman Mydin and Wang, 2011). The first term is the gas thermal conductivity without the effect of thermal radiation and the second term represents the effect of radiation within the air pores.

Hence, the effective thermal conductivity-temperature relationship of 650 kg/m^3 density foamcrete consists of three parts as demonstrated in Fig. 9: (i) Constant thermal conductivity up to 90°C before water evaporation, equal to that at ambient temperature reported by the manufacturer; (ii) Linear reduction of conductivity to 0.14 W/m.°C at 170°C; (iii) Non-linear increase in thermal conductivity based on Eqs. (30).

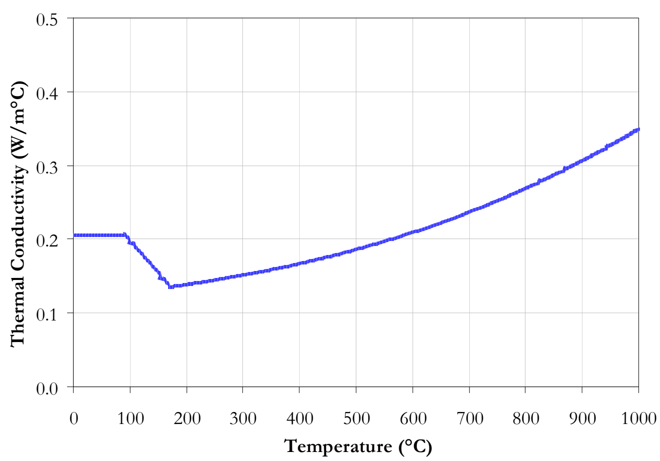

Fig. 9: Effective thermal conductivity of foamcrete as a function of temperature

Small Scale Test on Foamcrete Panel:

Fig. 10: Preparation of 650 kg/m^3 density foamcrete prototype panel with dimensions of 430 mm x 415 mm in plan and 150 mm in thickness for small scale fore test.

Small-scale experiments have been performed on 650 kg/m^3 density foamcrete slab. All foamcrete slab specimens had dimensions of 430 mm x 415 mm in plan and 150 mm in thickness (Figure 10). Each specimen was placed horizontally on top of an electric kiln as the source of heat, so that one side of the panel was subjected to kiln temperature and the other side faced up to the room temperature (19-25°C). The heating chamber has an internal diameter of 648 mm and 534 mm height. There was a 280 mm x 265 mm opening on the top lid of the kiln, which allowed exposure of the lower side of the panel to elevated temperatures. A 30 mm thick layer of glass wool with the same opening size was laid under the specimen to insulate the contact surface of the top lid. The kiln temperature was increased to about 1200°C.

Type K thermocouples were placed throughout the thickness of the foamcrete specimen at the centre of the slab to investigate temperature developments through each foamcrete panel. Five thermocouples were installed: on the exposed side, on the unexposed side and at quarter, half and three-quarter thickness, being 37.5mm, 75mm and 112.5mm from the heated surface. One thermocouple was place inside the kiln, at an approximate distance of 50mm from the exposed surface of the panel, to record the kiln temperature. Fig. 6 shows typical set-up of the experiments. Figures 11 visualizes the condition of the tested prototype foamcrete panels after exposure at elevated temperatures on top of an electric kiln as the source of heat

Fig. 11: Condition of prototype foamcrete panels after long hour's exposure at elevated temperatures on top of an electric kiln

Validation Of Thermal Property Models:

It is acceptable to assume that heat transfer in the test samples is one-dimensional in the thickness direction of the foamcrete slab (Othuman Mydin and Wang, 2011). All the measured experimental temperatures at all recording locations of the test specimens were compared with numerical analysis results. Thermal property values (theoretical thermal property model results) are considered and their prediction results compared. As mentioned previously, the exposed surface temperatures are used as input data in the heat transfer analysis to eliminate uncertainty in the thermal boundary condition on the exposed side. Figures 12-15 compare the measured and numerical analysis results for the 650 kg/m^3 density specimens. The results shown in Figures 12-15 clearly indicate close agreement between prediction and measured results of temperature throughout the thickness of the foamcrete samples.

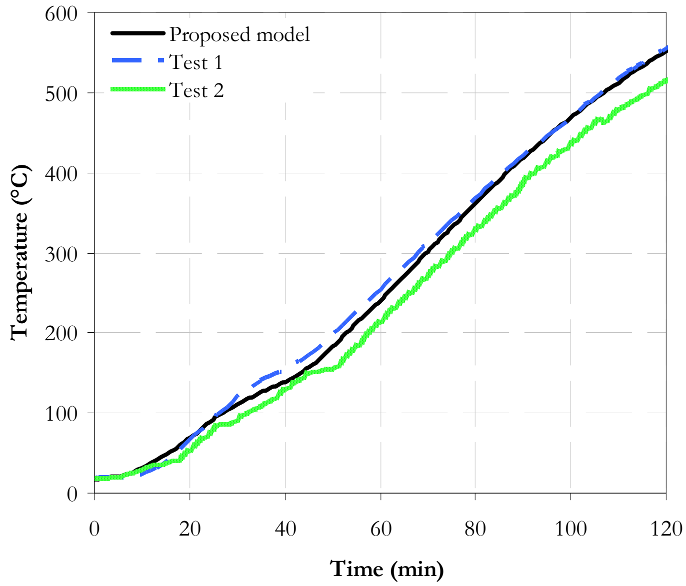

Fig. 12: Comparison between test results and numerical analysis at 37.5mm from exposed side

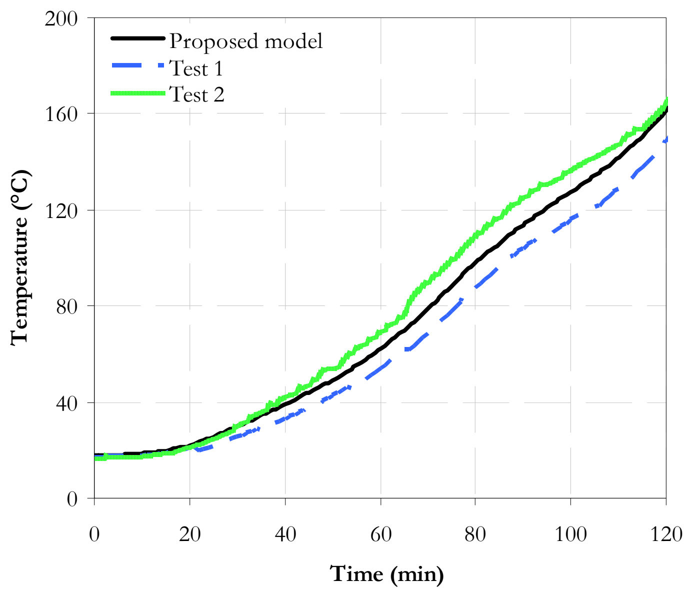

Fig. 13: Comparison between test results and numerical analysis at 75.0mm from exposed side

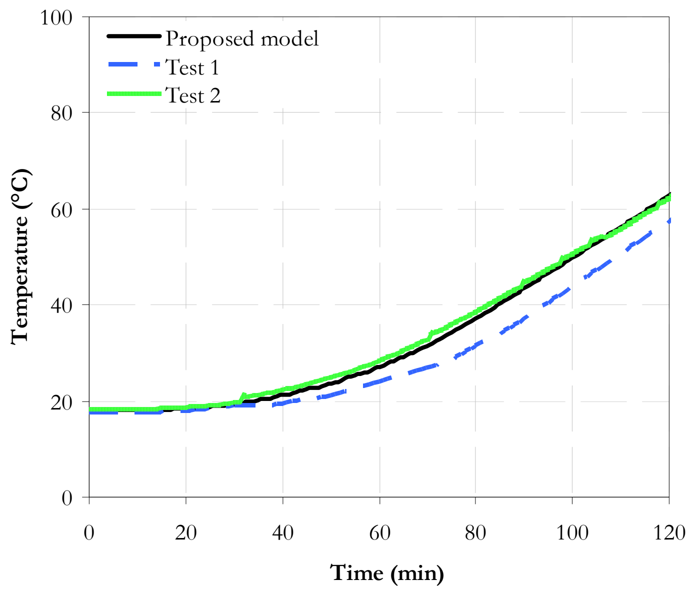

Fig. 14: Comparison between test results and numerical analysis at 112.5mm from exposed side

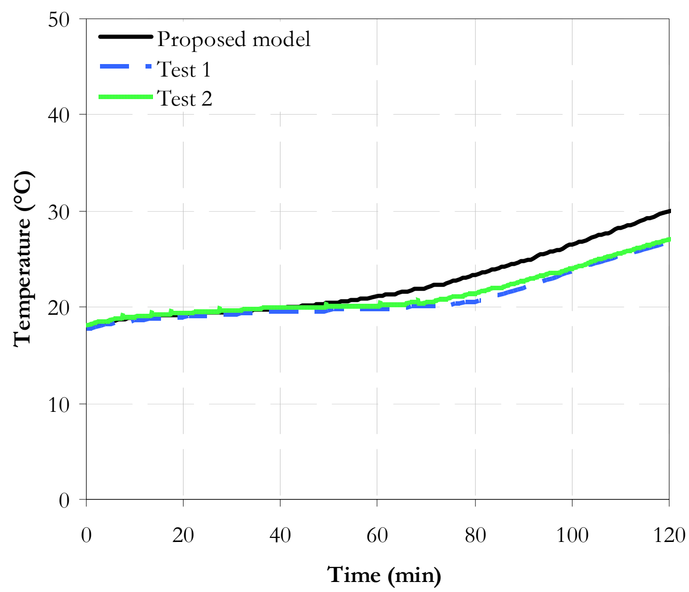

Fig. 15: Comparison between test results and numerical analysis at unexposed side

Conclusions:

This paper has presented the basis of the one-dimensional heat transfer modelling, the implementation of the method and the validation of thermal properties model of foamcrete panel. The comparison of test results with the numerical heat transfer analysis results using the proposed thermal property models is close, confirming the validity of the thermal conductivity models. Despite simplicity, the aforementioned analytical models for specific heat and thermal conductivity of foamcrete of different densities give accurate results. The proposed model is straightforward yet proficient and can be exploited to assist manufacturers to develop their products without having to carry out numerous large-scale fire tests in the future.

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