On Heat Transfer - Stress Analysis of Modified Brick (Reed Filler) Upon Its Production Stage

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Abstract. This paper aimed to scrutinize how burning process in modified brick’s production impinge on crack as a result of stress differentiation between two consecutive layers of the brick’s element. Diffusion engages in burning process of bricks, hence it generates thermal stress on element for different temperature between layers. This research focused on burning process in traditional production ward. Analytical of nonlinear equation and numerical solution, finite difference, were involved to obtain temperature value in each layer, followed by stress calculation. Based on the results, it can be concluded that crack occurs particularly on boundary area, since diffusion tends to yield relatively more different value on it. Therefore, certain strategies, that may decrease this differentiation, are required to minimize number of cracks during brick’s production.

1. Introduction

Nowadays, bricks are still more preferable building material for housing, especially for wall elements. Moreover, in accordance with environmental issue, utilization of waste and/or recycled material is also gain considerable concern from researchers. Some waste i.e sawdust, reed, sago husk, with their combination with additive material, have been used in brick’s production as filler and demonstrated enhanced performance in terms of physical and mechanical properties of bricks [1, 2, 3, 4].

Brick is one of the materials created from burned clay in relatively high temperature. The clay is raw ingredient in the manufacture of bricks that has plasticity and dry shrinkage properties. Plasticity on clay is essential to simplify the process in commencing the manufacture of bricks. should clay be excessively plastic, it has an effect on strength, shrinkage, and outcome number of bricks.

Production of bricks are consisted of preparation, molding, drying, burning, unloading/storaging respectively [5, 6, 7]. The process of burning of bricks should be in balance with the rise in temperature and its speed through several required steps to be considered, i.e evaporation/drying, oxidation stage, full combustion stage, and detention stage. At the stage of full combustion, bricks are burned until cooked and sintering process occurs up to be a solid brick. Temperature of burning process in traditional industries varies between 450 °C – 920 °C depended on the nature of the clay.

In the burning process, diffusion ensues, in which the heat flow is going through an object in the form
of bricks with dimensions and time. Diffusion process is also related to the strain and stress. Strain occurs due to temperature changes in the structure of the bricks through the process of diffusion combustion. Strain is associated with stress, in which case there will be a tension strain, as a result of elasticity properties of solid materials.

The purpose of this study was to determine the behaviour of stress and strain during burning process of bricks as a result of temperature change.

2. Materials and Method

2.1 Bricks Modelling

As shown on Figure 1, the dimension of bricks in this study followed the standard (5 x 11 x 22 cm) [8, 9, 10, 11, 12, 13, 14]. Brick has to have sharp and rectangle side; raft flat surface, a red color, sonorous sound when it is knocked, have no crack and not easy to be broke. These was the final condition of the brick prior to distribution to market. However, the initial condition of the bricks prior burning was different in terms of humidity. The classification of brick is following previous research [2,3,4], silty clay with sand.

![FIGURE 1. Brick’s Dimension](image)

2.2 Burning Process

There are 4 (four) stages during burning process as follows. The first stage is the evaporation (drying), i.e. the discharge of water forming the bricks, going up to a temperature of approximately 130 °C. Next, oxidation stage is where remained of plants (carbon) contained in the clay are burned. This process takes place at a temperature of 200 °C to 280 °C. Then, full combustion stage which cooked bricks are sintered to be a solid brick and temperatures vary between 350 °C and 600 °C depending on the nature of the clay. Finally, detention phase, where there is detention of temperature for 1-2 hours. In first to third stage, the temperature rise should be in slowly manner, in order to avoid losses on the brick.
2.3 Analytical and Numerical Formulation

Analytical solution is the implementation of diffusion equations 1D, Laplace and Poisson 3D, and finite difference methods in the process of burning the bricks to obtain the temperature difference between layers ($\Delta T$). The formulation of diffusion, Laplace and Poisson are shown respectively in equation 1-3 [15, 16, 17, 18]

\[
\frac{dT}{dt} = k \frac{d^2T}{dx^2} \quad (1)
\]

\[
\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2} = 0 \quad (2)
\]

\[
\frac{dT}{dt} = k \left[ \frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2} \right] \quad (3)
\]

Where $T$ is temperature in $^\circ C$, $t$ is time in second, $x, y, z$ (figure 3) are coordinate in Cartesian space in representing bricks dimension and $k$ is thermal conductivity.

2.4 Finite Difference Method

Finite difference method to be applied is the central difference method with Dirichlet boundary conditions as follows ($T = u (x, y) = \Delta T$) [19, 20, 21]
\begin{equation}
\frac{d^2 T}{dx^2} = \frac{T_{i,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}}{\Delta x^2}
\end{equation}

\begin{equation}
\frac{d^2 T}{dy^2} = \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta y^2}
\end{equation}

\begin{equation}
\frac{d^2 T}{dz^2} = \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta z^2}
\end{equation}

\begin{equation}
\frac{dT}{dt} = \frac{T_{i,j,k}^{n+1} - T_{i,j,k}^{n}}{\Delta t}
\end{equation}

2.5 Stress-Strain Relationship

An element experiencing temperature difference generates strain and stress. In this study, a simple approach in determining stress in bricks is formulated in equation 8 and 9.

\[ \varepsilon_T = \alpha(\Delta T) \]  \hspace{2cm} (8)
\[ \sigma_T = E_B \times \varepsilon_T \]  \hspace{2cm} (9)

Where \( \varepsilon_T \) is thermal strain, \( \alpha \) is thermal coefficient in \( ^\circ \text{C}^{-1} \), \( \Delta T \) is temperature difference in \( ^\circ \text{C} \), \( E_B \) is modulus of elasticity in \( \text{Mpa} \) and \( \sigma_T \) is thermal stress in \( \text{Mpa} \).

3. Results and Discussion

3.1 Temperature Change

Figures 4-7 shows temperature change at 4 (four) stages of burning process in 2 cm height. In terms of time, there is no significant difference among first three stages. Temperature change is sharply rising at 4\textsuperscript{th} stage, where burning temperature hit 600 \( ^\circ \text{C} \), e.g. \( \Delta T (5, 3, 2, t_3) = 107.664 \, ^\circ \text{C} \) and \( \Delta T (5, 3, 2, t_4) = 216.394 \, ^\circ \text{C} \). Temperature change is in proportional with burning duration, as can be seen first 20 minutes, then second 20 minutes, followed by 30 minutes and last 50 minutes.

FIGURE 4. Temperature Change (celcius degree) in First Stage at z = 2 cm
In space point of view, there is considerable temperature difference at start and end point in bricks, e.g. $\Delta T (11, 2, 2, t_4) = 253.239 \, ^\circ C$ and $\Delta T (11, 3, 2, t_4) = 215.872 \, ^\circ C$. Temperature change in around middle part of bricks share approximately similar value. Moreover, there is about 80 $^\circ C$ difference between bottom and top layer of brick’s element.
3.2 Stress Distribution

Subsequent to temperature analysis during burning period, stress analysis is performed, as can be seen on Figures 8-9. Figure 8 shows stress analysis on y-z plan, and figure 9 shows stress analysis on x-z plan. In accordance with temperature analysis, since linear proportional relationship between temperature change and stress, in terms of time, there is no significant difference among first three stages. Stress distribution is sharply rising at 4th stage, e.g. \( \sigma (5, 3, 2, t_4) = 36.6 \text{ Mpa} \) and \( \sigma (5, 3, 2, t_3) = 18.1\text{ Mpa} \)

![FIGURE 8. Stress Distribution for All Stages at y = 3 cm, z = 2 cm](image1)

![FIGURE 9. Stress Distribution for All Stages at x = 11 cm, z = 2 cm](image2)

In terms of position, there is clear difference at start, middle and end point in bricks, e.g. \( \sigma (11, 2, 2, t_4) = 42.8 \text{ Mpa} \) and \( \sigma (11, 2, 6, t_4) = 19.8 \text{ Mpa} \). Stress distribution tends to increase at start and end position. This stress distribution may generate crack as if the stress value pass over stress capacity of bricks, both compressive and tensile stress.

4. Conclusion

From the analytical and numerical evaluation, the study has demonstrated that stress distribution in bricks during burning process through 4 (four) stages can be completed by diffusion process, finite difference method, and stress-strain calculation. Space and time are significant variables in establishing temperature change and stress distribution during the burning process. Larger stress in start and end position of bricks may engender crack. This can be avoided by controlling heat transfer inside the bricks.
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