An Improvement on Heat Reduction in a Lightweight Composite Roof Material

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Abstract. The objective of this research is to improve heat reduction in a lightweight composite roof material. This research has studied and compared roofing material with opening for ventilation and without opening. A comprehensive model is simulated from computational fluid dynamics simulation of a finite element software. The simulation considered three aspects of heat transfer which are heat conduction, heat convection and radiation. The simulation result showed that the roofing material with opening for ventilation can reduce temperature in the composite roof about 20%

1. Introduction

Roofing materials are made of various kinds of materials by depending on people demand for example zinc, metal sheet, concrete tile and ceramic as well as composites.

Composite materials are made from two or more materials with different properties combined to produce a new material. Physical and chemical properties of each of the constituent materials remain distinct in the new material. These constituent materials work synergistically to produce a composite material that has improved properties when compared with the individual constituent materials.[1] Therefore, properties of the composite material cannot be predicted from any type of material, The constitutive equations in the finite element software can be used to simulate deflection behaviors of a linear composites material.[2]

Heat transfer is a movement of thermal energy from one object to another object of different temperature. There are three different ways the heat can be transferred by conduction (through direct contact), convection (through fluid movement) and radiation (through electromagnetic waves).

1. The concept of conduction is carried out in the case of the two objects in contact. Heat is passed from the higher temperature to another lower temperature. Conductive heat losses that occurred on a material sheet are due to thermal gradients between the material sheet and ambient surrounding condition that the solar panel connected [3]. In a rectangular coordinate, Heat transfer in one dimension can be calculated by Equation (1)

\[ Q = kA \frac{T_h - T_c}{\Delta x} = -kA \frac{T_c - T_h}{\Delta x} = -kA \frac{\Delta T}{\Delta x} \]  

(1)

Where:  
Q = Heat transferred per times (W)  
k = Thermal conductivity (W/m°C)  
A = Heat transferred area (m²)  
T_h = Maximum Temperature (°C)  

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\( T_c \) = Minimum Temperature (°C)
\( \Delta T \) = Temperature difference between (°C)
\( \Delta x \) = Thickness (m)

2. Convection heat transfer is the transfer of heat by movement of a fluid from higher temperature region to the lower temperature one. Generally, liquid and gas are the dominant form of this heat transfer. Convection heat transfer can be occurred either natural convection or forced convection. The natural convection is triggered by density differences within fluid that happened due to temperature gradient and without any external source of support. Forced convection is movement of the fluid that is produced by an external source. By Newton’s law of cooling, the rate of convective heat transfer can be calculated \([4]\) as given by Equation (2)

\[
Q = hA(T_s - T_f)
\]  \hspace{1cm} (2)

Where:  
\( Q \) = Heat transferred per times (W)  
\( h \) = Heat transferred coefficient (W/m°C)  
\( A \) = Cross section area (m²)  
\( T_s \) = Temperature of the solid (°C)  
\( T_f \) = Temperature of the fluid (°C)

3. Radiation heat transfer is not similar as the concept of conduction and convection. Both conduction and convection is the transfer of heat via matter. While, radiation transfers the heat in form of electromagnetic waves. Radiation is the heat transfer from the body according to the temperature; it increases as the body temperature increases. When the heat reaches to another surface of the body, they may be absorbed, reflected or transmitted. The emitted energy by a blackbody \([5]\) is given by Stefan-Boltzmann law as Equation (3)

\[
Q = \varepsilon A \sigma T_A^4
\]  \hspace{1cm} (3)

Where:  
\( Q \) = Heat transferred per times (W)  
\( \varepsilon \) = Stefan - boltzmann constant (W/m²K4)  
\( \sigma \) = Stefan - boltzmann constant (W/m²K4)  
\( \varepsilon \) = Infrared emissivity  
\( T_A \) = Effective radiating temperature (K)

This heat energy can be transferred away by the fact that heat is transferred to the conduction via matter from particle to particle. Convective heat transfer of the entire roofing material caused by wind. Solar radiation reaches on roofing material as shown in Figure 1.
The aim of this work is studied on heat transfer behaviors of a roofing material. This research is divided into two models; Firstly, Roofing material with opening for ventilation. Secondly, Roofing material without opening for ventilation the heat transfer behaviors is analyzed from a finite element software in computational fluid dynamics simulation.

2. Method

2.1. Geometry Model of Finite Element.

The roofing material model consists of two composite materials. The composite material A and B as shown in Figure2. The composite material A has size of 88×60×4cm and material B has size of 120x99x1.25cm. The demonstration divided into two models; Firstly, Roofing material with opening for ventilation below the composite material A as shown in figure3. Secondly, Roofing material without opening for ventilation as shown in figure4.

![Figure 2. Pattern of composite roofing material](image1)

![Figure 3. Roofing material with opening for ventilation](image2)
2.2. Materials Properties

The material properties of the considered specimen consist of Density ($\rho$), Thermal Conductivity (K), Specific Heat (Cp) following table I

| Materials | Thermal Conductivity, K (W/m°C) | Specific Heat, Cp (J/kg°C) | Density $\rho$ (kg/m$^2$) |
|-----------|---------------------------------|---------------------------|--------------------------|
| A         | 1.8                             | 500                       | 3000                     |
| B         | 0.42                            | 921                       | 1430                     |

2.3. Boundary Condition

Finite Element Model for analysis heat transfer behaviors of composite roofing material is prepare in a software for computational fluid dynamics simulation.

Both the initial temperature of composite material the model and ambient temperature are defined at 30 °C.

Beside, no-slip in boundary condition between composite material is prescribed.

By using mesh generation of the composite roof with type of element of SOLID186 and SOLID187, The model of roofing material with opening for ventilation and without opening have the number of elements 920,652 and 929,813 respectively as shown in figure5 and figure6.

![Figure 5. Roofing material with opening for ventilation model was meshing.](image-url)
Figure 6. Roofing material without opening for ventilation model was meshing.

According to the computational fluid dynamics simulation, the model was specified two surfaces which normal to Z axis to be an inlet and outlet surface. Beside, other surfaces being normal to X axis as specified as wall condition as written in figure 7.

Figure 7. Boundary condition model of Computational Fluid Dynamics Domain.

2.4. Load Input

The initial temperature from solar radiation has 60°C at top surface of composite material A and B.

Applied wind with velocity 1m/s and ambient temperature 30 °C flows beneath composite roofing material, the wind passes through the inlet and outlet as shown in figure 7.

3. Result

The result from simulation of the A composite material with opening for ventilation has maximum temperature at top surface about 42.3 °C as shown in figure 8. and at bottom surface about 42.1 °C as shown in figure 9. The result from stimulation test of the A composite material without opening for ventilation has maximum temperature at top surface about 52.7°C as shown in figure 10. and at bottom surface about 52.6°C as shown in figure 11. The figure 12 shown comparing the temperature of composite material A with opening and without opening.
Figure 8. Temperature distribution at top surface of composite material A of roofing material with opening for ventilation

Figure 9. Temperature distribution at bottom surface of composite material A of roofing material with opening for ventilation

Figure 10. Temperature distribution at top surface of composite material A of roofing material without opening for ventilation
4. Conclusion

The result from simulation model of the A composite material with opening for ventilation has maximum temperature at top surface about 42.3 °C and at bottom surface about 42.1 °C. The result from stimulation test of the A composite material without opening for ventilation has maximum temperature at top surface about 52.7 °C and at bottom surface about 52.6 °C. To summarize as the
result, that roofing material with opening ventilation could reduce temperature in the A composite material about 20% under specified conditions. This paper gives a guideline to develop composite material roofing in the future.

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