Experimental study of thermal behavior of heated Natural Composite Materials

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Abstract. An experimental investigation was carried out for the thermal behavior of horizontal heated natural composite material plates; (polyester resin mixed with seed dates, or egg shells, or and feathers) with different volume fraction (10%, 20%, and 30%). Natural composite materials are heated with different heat flux (1078W/m², 928W/m², 750W/m², 608W/m², and 457W/m²). Experimental test rig is used to measure the temperature distribution upper surface of composite materials. Also the thermal properties (thermal conductivity, specific heat, and thermal diffusivity) of natural composite materials are studied. The results show that the maximum value of temperature occurs at the mid-point of all types of natural composite material plate when the volume fraction equal to 30% and the heat flux equal to 1078 W/m². Results show that the thermal conductivity for seed dates composite material, the specific heat for feathers composite material and the thermal diffusivity for seed dates composite material are higher value when the volume fraction equal to 30%.

1. Introduction

The natural convection are utilizes in mechanical applications such as the electrical and electronic applications generators, transformers, and electronic circuits [1]. Pera and Gebhart [2], studied numerically and experimentally the boundary layer flow for laminar natural convection heat transfer at semi-infinite horizontal plates and inclined at constant temperature and heat flux. Governing equations are solved numerically at Prandtl number (Pr=0.7), constant temperature, and at range of Prandtl number (0.1<Pr<10) at constant heat flux. Hassan and Mohammed [3], studied experimentally of laminar natural convection heat transfer from rectangular plates at horizontal, vertical and inclined heated at constant temperature. The inclined plates were positive and negative angles (0°, 15°, 30°, 45°, 60° and 90°), the positive angle when a heated upward – facing and negative when a heated downward – facing within (1.1×10³< Gr cos θ < 3×10⁸), air is used as a heat transfer medium. The plate fabricated from brass has dimensions (0.504 m × 0.2 m) is heated by hot water upward to constant temperature. They obtained that the mean of heat transfer in vertical position is higher than horizontal in both cases. When increasing the inclined angle the mean heat transfer is decreased. The mean heat transfer heated downward – facing less than upward – facing. Good agreement between the experimental and theoretical results to Gr cos θ < 3×10⁶. Miyamoto et. al. [4], studied numerically the heat transfer from rectangular surfaces at vertical and horizontal position. Heated in a constant heat flux and temperature. The governing equations were solved using finite difference method to solve the Navier – Stokes and other energy equations. They obtained the relation between the mean Nusslet number and Grashof number at Prandtl number (Pr=0.72). The results which obtained for Nusslet...
number is less from previous experimental results but behavior of the Grashof number and Nusslet number is agreeing to behavior of previous experimental researches. They studied effect of thickness of plate on local heat transfer coefficient. Lino et al. [5], studied experimentally and numerically the natural convection heat transfer on a vertical flat plate, subjected to a constant heat flux. The experimental study was performed on an experimental setup designed in order to assuming with a good approximation. The numerical simulation of the flow made by the CFX-5.5.1 code from the AEA technology solves the flow respecting the geometry, the initial and boundary condition utilized in the laboratory. Qasim et al. [6], studied experimentally and numerically the natural convection heat transfer from isothermal natural composite materials (seed dates, egg shells, and feathers) with different volume fraction. The experimental results are obtained at Rayleigh numbers \(6.1 \times 10^5 \leq \text{Ra} \leq 7.7 \times 10^5\). The results show that the value of temperature and its distribution is related to the percentage of volume fraction and the heat flux. Qasim et al. [7], investigated the laminar natural convection heat transfer from natural composite material at (vertical, inclined and horizontal) position numerically. Continuity and Navier Stocks equations are solved in three dimensions. Numerical results showed that the plumes and temperature distribution are affected by the air and the distance from heat source. The aim of present paper is to investigate the thermal behavior of horizontal heated natural composite material plates experimentally.

2. Experimental Work. Methods and Materials

The experimental work consists of preparing a natural composite material specimen as a test plate. To investigate the thermal behavior of test plates, an experimental test rig was built up. Many types of natural materials are used with polyester-matrix to prepare the composite material. These types are (egg shell, seed dates, and feathers). The weight of natural materials used with the composite materials is different which depends upon the volume fraction. The ratio between the volumes of fiber (egg shell or seed dates or feathers) to total volume of composite material is the volume fraction as shown in the following equation (1): [8]

\[
\%V_{\text{fraction}} = \frac{V_{\text{fb}}}{V_{\text{total}}} \tag{1}
\]

The volume of each sample is found after determining the length, width and the thickness of each type of natural composite materials plate according to the following equation(2): [8]

\[
\Psi = L \times W \times \delta \tag{2}
\]

The densities of the used samples are found by using the following equation (3): [8]

\[
\rho = \frac{m}{\Psi} \tag{3}
\]

Glass mold is used to fabricate the natural composite material plates. The mold dimensions were made to give net specimen dimension of \((30\text{cm} \times 20\text{cm})\) and the thickness is \((0.6\text{cm})\). The first step is to smear the mold with special kind of oil to prevent direct contact between the specimen and the mold. The mold consists of three parts; base, removable barrier, and cover. After molding, the sample cover is used to apply pressure equally all over the sample to eliminate any air gap trapped in the sample. The test rig used in experimental work is shown in figure 1. The construction consist of; mica, glass wool with thickness (2cm), cork board with thickness (2.5cm), copper plate has dimensions \((30\text{cm} \times 20\text{cm})\) and thickness \((0.175\text{cm})\), specimens of natural composite materials. Thermocouples type “k” are distributed uniformly and fixed at the bottom surface of a hot plate on (24) locations. The location distance is \((2.5\text{cm})\) from the edges and \((5\text{cm})\) between the thermocouples, as shown in figure 2.
Electrical heaters are used to heat the natural composite materials specimen. Heaters consist of thin ribbon of nichrome having width (1mm) and thickness (0.06 mm). The heaters are feed by the current across the varic device. This is used to control the heat flux through the current across the heater which recorded in the ammeter and voltage which recorded the voltmeter, as shown in figure 3.
The test rig is insulated from bottom and also all sides (except the top surface of plate) by the glass wool, corkboard. The layer of mica is reduced the thermal losses, as shown in figure 4. To measure the temperature for both test rig sides and its lower surface, laser thermometer device is used. Digital reader is used to read the temperature of wall plate by thermocouples which are fixed in the specimen; the test rig is placed in a laboratory which is having dimension (2 m × 2 m × 2.5 m).

Many parameters will be calculated from experimental work as follows:

- **Heat Flux:**
  
  The calculation of power for the heaters is: [8]

  \[
  Q = V.I \text{ (Watt)} \tag{4}
  \]

  \[
  \text{(Heat flux)} \quad q = \frac{Q}{A_t} = \text{Watt} / \text{m}^2 \tag{5}
  \]

  Where \( A_t \) is the area of the element (30 cm × 20 cm).

### 3. Results and Discussions

This result of thermal conductivity, specific heat, and thermal diffusivity are measured experimentally using hot disk technique. Figure 5 gives the relationship between thermal conductivity (\( k \)) and volume fraction (\( V_f \)) with different types of natural composite material. Figure 5 shows an increase in the thermal conductivity of the composite material in the case of mixing the eggshells or seed dates powder by 30% (volume fraction) with polyester resin, while the behavior of thermal conductivity is the opposite when mixing the feathers. The conductivity of the natural composite material increases by 20% when adding seed dates to with polyester resin by 30%. Figure 6 shows the value of specific heat for different types of natural composite materials with different volume fraction. The figure shows the specific heat behavior with an increase in the percentage of additives with polyester resin. This behavior is the opposite of the behavior of thermal conductivity, where the specific heat increases by 11% when mixing feathers by 30% with polyester resins.

Figure 7 gives the relationship between thermal diffusivity (\( \alpha \)) and volume fraction (\( V_f \)) with different types of natural composite material. The figure shows that thermal diffusivity increases significantly when mixing seed dates with polyester resin, where the increase is 33% at a mixing rate of 30%. While the thermal diffusivity of other natural composite materials decreases gradually by increasing the volume fraction. Figure 8 shows the temperature distribution for seed dates composite materials at different positions of X-axis (distance) with different values of heat flux. It can be seen that, the maximum value of temperature occurs at heat flux \( q=1078 \text{ W/m}^2 \).
Figures 9 and 10 show the same relations as in figure 8, but now for another volume fraction (20% and 30%) respectively. We notice from figure 10 that there is an increase in the temperature behavior of the natural compound material when the heat flux value is 1078 W/m², and the increase is about 6% when the mixing ratio is 30%.

Figures 11, 12 and 13 show the distribution of temperatures on the surface of the natural composite material when adding egg shells to polyester resin by (10%, 20% and 30%). The increase in temperature from figure 13 is 7% when the heat flux is 1078 W/m² compared to figure 11. As we note from figure 12 the behavior of temperatures increases significantly when the heat flux is 457W/m².
Figures 14, 15 and 16 show the distribution of temperatures on the surface of the natural composite material when adding feathers to polyester resin by (10%, 20% and 30%). The increase in temperature from figure 16 is 2% when the heat flux is 1078 W/m² compared to figure 14. As we note from figure 15 the behavior of temperatures increases significantly when the heat flux is 457 W/m².

4. Conclusions

Experimental study of thermal behavior of natural composite materials under various effects are presented and interpreted. It is concluded that the increase in volume fraction will lead to an increase in the thermal conductivity for egg shells and seed dates composite materials. But, this will decreases the thermal conductivity of feathers composite materials. As the volume fraction increases, the specific heat for feathers composite materials will be increased. But this will decreases the specific heat of egg shells and seed dates composite materials. Increasing the volume fraction will lead to an increase in the thermal diffusivity for seed dates composite materials. However; this will lead to a decrease in the thermal diffusivity of egg shells and feathers composite materials. The temperature distribution increases due to the increase in volume fraction for the seed dates, egg shells, and feathers composite materials. The temperature distribution increase due to the increase in heat flux for [(the seed dates 10%, 20% and 30% volume fraction), (egg shells 10%, 20% and 30% volume fraction) and (feathers 10%, 20% and 30% volume fraction)] composite materials.

Nomenclature

| Letter | description | unit |
|--------|-------------|------|
| A_s    | Area of the element | m²   |
| q      | Heat flux    | W/m² |
| I      | Current      | Amp. |
| V      | Voltage      | V    |
\[ \begin{align*}
L & \quad \text{Length of composite materials} \quad \text{m} \\
\delta & \quad \text{Thickness of fiber samples} \quad \text{m} \\
W & \quad \text{Width} \quad \text{m} \\
\forall & \quad \text{Volume} \quad \text{m}^3
\end{align*} \]

5. References

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