THEORETICAL AND EXPERIMENTAL INVESTIGATION OF NATURAL COMPOSITE MATERIALS AS THERMAL INSULATION

Dr. Fadhel Abbas Abdullah
AL-Mustansiriya University, College of Engineering

ABSTRACT

Theoretical and experimental investigations of composite material as thermal insulation consists of natural fibers (White feather, Jute, Egg shell, and Black feather) are present in this work. The experimental works are divided into two parts. The first part involved with the study of the thermal conductivity of the composite materials. Lee's disc method is used to measure the thermal conductivity of different types of natural composite materials. These values are compared with theoretical values of thermal conductivity calculated using Maxwell model. The effect of volume fraction on thermal conductivity is studied. The second part included building two rigs which have the dimensions (1m X 1m X 1m). The first rig used as reference and the second rig to measure the temperature distribution on the lower surface of the roof insulation. The effects of change in volume fraction, air gap, and types of natural composite insulation on temperature reduction are investigated. The results show that the (Jute composite material) gives good results as composite thermal insulation compared with other natural composite materials.

KEYWARDS: - composite material, thermal conductivity, insulation, natural fiber

الخلاصه

في هذا العمل تم التحقيق النظري و التجريبي للمادةِ المركبة كعازل حراري باستخدام الالياف الطبيعيةِ (ريشة الدجاج الابيض، نبات الجوت، قشر البيض، ريشة الدجاج الاسود). يقسم هذا العمل إلى قسمين: يتضمن القسم الاول قياس الموصلية الحرارية للمواد المركبة الطبيعية باستخدام تقنية (اقراص – لي).تمت مقارنة النتائج العملية للموصلية الحرارية مع النتائج النظرية المحسوبة باستخدام (نموذج ماكس ويل). تم دراسة تاثير قيم الكسر الحجمي على قيم الموصلية الحرارية. في القسم الثاني تم بناء هيكلين إبعاد كل منهما (١مX١مX١م) ، الهيكل الاول يعتبر مصدر اساس لدرجات الحرارة المقاسة اما الهيكل الثاني فيستخدم لاختبار العوازل الحرارية وقياس درجة الحرارة على السطح السفلي للسقف. اثبتت النتائج تاثير الكسر الحجمي، الفراغ الهوائي، بالإضافة إلى نوع العازل الطبيعي على مقدار التخفيض في قيم درجة الحرارة. وبينت النتائج إن استخدام العوازل الطبيعية المصنوعة من مادة نبات الجوت تعطي نتائج جيدة في العزل الحراري بالمقارنه بالمواد المركبة الطبيعية الاخرى.

NOMENCLATURE

Letter	Description	Unit
d	Diameter of sample	m
IV	Rate of energy supply to the heater	W
k	Thermal conductivity of composite	W/m.K
k1, k2,…,kn	Thermal conductivity of each layer of roof assembly	W/m.K
k_f	Thermal conductivity of fiber	W/m.K
k_m	Thermal conductivity of matrix	W/m.K
Q	Total heat gain	W
V	Volume of sample	m^3
v_f	Volume fraction	--------
V_{fiber}	Volume of fiber	m^3
V_{total}	Total volume	m^3
T_A, T_B, and T_C	Temperature of disc A, B, and C in Lee's disc technique	C°
ts	Specimen thickness	m
r	Radius of disc	m

1. INTRODUCTION

A Natural composite is a material formed by a matrix (resin) and a reinforcement of natural fibers (usually derived from plants or cellulose). Natural fibers have low thermal conductivity so this will give good ability for insulation with other materials. High aspect ratio (length/diameter) permits effective load transfer via the matrix (**Rao et. al., 2007**). Natural fibers are grouped into three types: seed hair, bast fibers, and leaf fibers, depending upon the source. Some examples are cotton (seed hairs), ramie, jute, and a flax (bast fibers), and sisal and abaca (leaf fibers). Of these fibers, jute, ramie, flax, and sisal are the most commonly used fibers for polymer composites (**Yan et. al., 2007**).

(**Dell, 1997**) used Jute fiber nonwoven mats to reinforce resin transfer molded unsaturated polyester-styrene panels. Tensile strength and flexural modulus for unmodified jute samples were half that of samples made with a commercial glass mat. Jute fiber pull-out from the matrix was seen in scanning electron micrographs, which indicates that improving adhesion at the fiber-polymer interface may increase mechanical properties. (**Frydrych, et. al., 2003**) presented a comparison analysis of thermal insulation properties such as thermal conductivity, absorption and thermal resistance of fabrics made of cotton and Tencel. The finished fabrics made of Tencel yarn showed lower values of thermal conductivity and thermal absorption then fabrics made of cotton yerns, and higher values of thermal diffusion and resistance. (**Jerrold E., 2003**) made a series of aspen fiber medium density fiberboard panels adding various levels of chicken feather fiber to determine the relative effect of the feather fiber-wood fiber mixtures on composite panel properties. The mechanical properties show some loss in strength and stiffness for feather fiber-wood fiber mixtures when compared to the properties of all-wood control panels. The physical properties of feather fiber-wood fiber mixtures showed a marked improvement in resistance to water absorption. (**Tajvidi et. al., 2006**) deals with the effect of natural fibers on thermal and mechanical properties of natural fiber polypropylene composite using dynamic mechanical analysis. Results indicated that glass transition was slightly shifted to lower temperature in composite. Transition temperature was higher in case of composite and intensity was higher as well. (**Kock, 2006**) have been characterized the physical and mechanical properties of chicken feather materials CFM. Results describing the moisture content, aspect ratio, apparent specific gravity, chemical durability, Young's modulus, and tensile strength for processed CFM. (**Rao et. al., 2007**) obtained Short fibers form poultry feathers to possess high toughness, good thermal insulation properties, non abrasive behavior and hydrophobic nature. Mechanical properties such as tensile strength, and flexural strength were evaluated. It was found that the material loss from the composite surface depends greatly on operational variables like impact angle, impact velocity etc.

In this work the White Feather, Jute, Egg shell, and Black Feather were taken up and studied the thermal properties of them, also used them as thermal insulation on roof surface.

2. DENSITY AND VOLUME FRACTION OF NATURAL COMPOSITE MATERIALS

The density of the composite materials "thermal insulation" is found by measuring the weight and volume of the component of composite materials samples. The weight is found by using an electronic portion scale (up to 2000g). The thickness of each type of fiberglass was found by using dial calipers. The dimension of composite materials samples are (0.6 cm) thickness and (4 cm) diameter. The volume of each sample is found using equation (1).

$$V = (\frac{\pi}{4}) * d_s^2 * t \quad (1)$$

The measurement of weight and thickness were repeated three times for all types of natural fiber samples. An average value was taken for the calculations in this part. Then the density is calculated from volume and weight. The same procedure is repeated to determine the density of polyester resin which is found to be 1.1 g/cm3. **Table (1)** shows the experimental result of density for different natural fibers used in this work.

After determining the density and volume for each type of fiber, the volume fraction of each insulation type can be determined using the following relation.

$$v_f = \frac{V_{fiber}}{V_{total}} \quad (2)$$

The volume fraction is the ratio of fiber volume in composite to the total volume of composite which is consists of fiber and matrix (polyester resin). In this work many volume fraction are taken for different types of natural composite materials.

3. THEORITICAL CALCULATION OF THERMAL CONDUCTIVITY OF NATURAL COMPOSITE MATERIALS

The thermal conductivity of natural composite materials depends on thermal conductivity of natural fiber, thermal conductivity of matrix, and the value of volume fraction.

Maxwell Model (**Duncan, 2002**) is used to calculate theoretically the thermal conductivity of the samples of thermal insulation used in this research using equation (3).

$$\underline{k} = \frac{km\left[k_f + 2k_m - 2v_f\left(k_m - k_f\right)\right]}{k_f + 2k_m + v_f\left(k_m - k_f\right)} \quad (3)$$

4. THE MEASURMENT OF THERMAL CONDUCTIVITY OF NATURAL COMPOSITE MATERIALS

The cast iron mold is used to fabricate a samples of natural composite materials used to measurement the thermal conductivity using Lee's disk method, the cast iron mold was cleaned from dirt and then smeared with special oil to prevent direct contact between the sample and the mold, see **figure (1)** .The specimen have dimension of 4cm X 0.6cm as shown in **figure (2)**. Casting is put under load for about one to two hours for proper curing at room temperature will produce the samples shown in **figure (3)**.

Thermal conductivity coefficient of specimens was measured using Lee's disk method principle (**Faieza, 2006**). The apparatus shown in **figure (4)** consists of four identical discs of 4 cm in diameter and 0.6 cm thickness. One of them includes an electrical heater denoted by (H). The specimen (S) with 4 cm in diameter and (0.6 cm) thickness was placed between the discs (A) and (B), as shown in **figure (4)**. The heater (H) was sandwiched between the discs (B) and (C). Temperature of (A), (B) and (C) discs were measured using three thermocouples type (K). The temperature of the ambient was measured too. Heat was supplied with a 12 volt D.C. power supply and the current I was found to be equal to 0.26 Amp. The rate of supply energy was noticed (IV).

When the discs were assembled they are vanished to give them the same emissive, and the whole apparatus was suspended in an enclosure of constant temperature. Total heat (Q) can be obtained in terms of supply energy (IV), since the total heat supplied must be equal to that given up by the various surfaces (**Faieza, 2006**):

$$Q = VI\left(a_A T_A + a_S \frac{T_A + T_B}{2} + a_B T_B + a_C T_C\right) \tag{4}$$

So, thermal conductivity coefficient becomes: (**Faieza, 2006**)

$$K = \left(\frac{Q\,t_S}{T_B - T_A}\right)\left[T_A + \frac{2T_A}{r}\left(t_A + \frac{t_S}{4}\right) + \frac{t_S T_B}{2r}\right] \tag{5}$$

The average of five measurements was taken for each specimen to minimize the possible errors. Thermal conductivity of samples was then calculated theoretically by using Maxwell model as illustrated above where comparisons between theoretical and experimental results were accomplished.

5. COMPOSITE PLATE MANUFATURING

The composite plates used in this work consists from natural fiber (four types show in **table (1)**) and matrix (polyester resin with hardener 4%), without adding the hardener the polyester will stay liquid. To fabricate the composite plate of size (500mm X 500mm) with 6mm thickness as shown in **figure (5)**, the mixture (natural fiber and matrix) is cast in mould which made from glass show in **figure (6)**. This operation are done in a closed space and used buffer material to avoid direct contact between the specimen and the mould surface .After molding the sample insulating cover is used and apply distributed load to avoid keeping any air gap trapped in the sample for about 24 hours at room temperature.

6. THE RIGS MODEL

To investigate the effect of thermal insulation (Natural composite material) on the roof, two rigs were building to study the temperature fluctuation when the thermal insulation is installed. The two rigs are similar in construction and dimensions, their dimension (1m X 1m X 1m) as shown in **figure (7)**; the first rig is used as a reference to indicate the temperatures of the rig without thermal insulation and to compare it with the temperature of the second rig with the thermal insulation. The model is consist of an iron structure which is able to hold the weight of concrete roof which is located above the iron structure, the roof is made of concrete and its dimensions are (1m X 1m X 0.12m) to simulate the construction in Iraqi buildings. The structure of walls is made of (6 cm thickness) polystyrene to eliminate the effect of temperature gain through the walls of the models .The thermocouples are used to determine the temperature of the rigs and they are distributed on the bottom surface of the roof. Five thermocouples type (K) range (-30 Cº to 110 Cº) are used in order to avoid the error that may be happen and in average temperature of thermocouples in each location in the model are taken and the temperature will measured and listed in hourly in all days of experimental work. The thermal insulation will put on the top of the concrete roof with and without air gap. The air gap (if it's found) is put between the top surface of the concrete roof and the natural composite insulation, and it was 2cm above the roof.

7. RESULT AND DISCUSSION

This section includes experimental and theoretical results of the present work. Theoretical results represent the thermal conductivity of different type of natural composite materials with different volume fraction. The effects of different types of natural composite materials (thermal insulation) and the volume fraction on the temperature reduction of roof with and without air gap are also investigated.

7.1 Volume Fraction and Thermal Conductivity of Composites

The effect of volume fraction on thermal conductivity of composite material "thermal insulation" was investigated in this section.

Figure (8) represents a comparison between experimental and theoretical results of thermal conductivity varying with volume fraction using white feather. Theoretical results are calculated using Maxwell Model [see equation (3)]. From this figure, it can be seen that the experimental results gives accepted results in comparison with theoretical result, and with a maximum error percentage of (18.7 %). The thermal conductivity is decreasing with increasing the volume fraction due to increasing the white feather in composite insulated. The same comparison between volume fraction and thermal conductivity was repeated for black feather, egg shell, and jute in **figures (9), (10), and (11)** respectively. The maximum error percentage was found (14.5%), (18%), and (10.5%) respectively. **Figure (12)** shows the experimental relationship between volume fraction and thermal conductivity for different types of natural fibers. It is clear that the thermal conductivity decreases with increasing of volume fraction due to increasing the volume of natural fiber in composite sample which has less thermal conductivity than polyester resin, and the figure shows that the composite of jute have lower thermal conductivity than other types because the jute fiber has thermal conductivity less than the other natural fiber.

7.2 Roof Daily Temperature Distribution

Temperature of roof varies throughout the day due to solar radiation. It is also an effective indicator for heat transfer inside the space. Investigating the efficiency of composite materials as thermal insulation on roof requires measuring the temperature distribution on lower surfaces of the roof, with and without the insulation. The thickness of different natural thermal insulations was 6mm as explained in section 5. All the daily data was collected from 7 A.M. to 4 P.M. **Figure (13)** shows the daily temperature reduction with local day time on roof lower for white feathers composite insulation with 2cm air gap with different volume fraction. Temperature reduction is calculated from:-

$$T_{\text{reduction}} = T_{\text{from natural composite insulated rig}} - T_{\text{from refrence rig}} \qquad (6)$$

From this figure, it is clear that increasing volume fraction causes increasing in temperature reduction due to decreasing of matrix (polyester) which have thermal conductivity higher than thermal conductivity of fiber (natural fiber). This caused in increasing thermal conductivity of natural composite insulation. **Figure (14)** repeated same parameters in **figure (13)** except removing air gap. From this figure, it can be seen that, increasing volume fraction causes decreasing temperature reduction. From figures (13, and 14), using composite insulated with air gap 2 cm thickness **(see figure 13)** causes increasing in temperature reduction comparison with insulated without air gap **(see figure 14)** because the air has low thermal conductivity. The maximum temperature reduction was found (16.2 C^o and 12.2 C^o) in figures (13 and 14) respectively, it was occurs between 12 P.M. to 2 P.M. due to increasing the solar radiation at these time

Figs (15) and (16) give the temperature reduction for black feather with and without air gap respectively with changing volume fraction. Maximum temperature reduction was found (12.1 C^o

and 9.6 C^o) in figures (15) and (16) respectively. **Figures (17), (18), (19), and (20)** give same relationships as in figures (15) and (16) but now for egg shell natural composite material figures (17 and 18) and jute natural composite material figures (19) and (20). From these figures the maximum temperature reduction with and without air gap were (10.3 C^o and 7.1 C^o) for egg shell insulated (see figures (17) and (18)) and (16.8 C^o and 11.6 C^o) for jute insulated (see figures (19) and (20)). From figures (13), (14), (15), (16), (17), (18), (19), and (20), it can be seen that, the increasing volume fraction causes increasing temperature due to decreasing thermal conductivity of natural composite insulated. Also, using air gap will increasing reduction in temperature because the air gap has small value of thermal conductivity.

Figure (21) gives the relationship between temperature reduction and the local time for different types of natural composite materials with (10 %) volume fraction and with air gap. From this figure, the natural composite plate made from jute given reduction in temperature greater than other types of natural materials, and the egg shell natural composite materials gives minimum temperature reduction. **Figures (22) and (23)** give same relations as figure (21) with (30%, and 60%) volume fraction respectively. From these figures, it can be concluded that the jute natural composite insulated gives maximum reduction in temperature. Also, the increasing volume fraction will be increasing temperature reduction due to increasing volume of fiber which has thermal conductivity higher the matrix in composite plate.

8. CONCUSIONS

Many conclusions can be noticed from the present work which can be summarized, as follows:

1) Increasing volume fraction of natural fibers causes decreases in thermal conductivity and increases in temperature reduction of the roof.
2) The jute gives minimum thermal conductivity compare with other natural composite materials.
3) The maximum reduction of temperature is occurred in the period between (12 P.M._2 P.M.).
4) The jute and white feather gives maximum reduction in temperature comparing with other natural composite materials.
5) The air gap increases the temperature reduction.
6) Finally, the natural composite materials can be used as thermal insulation.

9. REFERENCES

1) Duncan M. Price, Mark Jarrat, “Thermal Conductivity of PTFE and PTFE Composites", Thermo chi mica Act 392-393 (2002).

2) Faieza M. saleem;" thermal and mechanical Investigation of Fiber reinforced epoxy" Ph.D Thesis, Mech. Eng. Department, University of Technology, Iraq, 2006.

3) I. Frydrych, G. Dziworska, J. Bilska ;” Comparative Analysis of the Thermal Insulation Properties of Fabrics Made of Natural and Man-Made Cellulose Fibres”, Fibres & Textiles in Eastern, October/December 2002.

4) Jane L. O’Dell,” Natural Fibers in Resin Transfer Molded Composites”; The fourth International Conference on Woodfiber-Plastic Composites, May 12-14, 1997.

5) Jerrold E. Winandy1, James H. Muehl1, Jessie A. Micales1, Ashok Raina and Walter Schmidt;” Potential of Chicken Feather Fibre in Wood MDF Composites “Queen Mary, University of London September 1-2, 2003.

6) Jeffrey W. Kock;” PHYSICAL AND MECHANICAL PROPERTIES OF HICKEN FEATHER MATERIALS”, M.Sc. Thesis. School of Civil and environmental engineering, Georgia institute Of technology, May, 2006.

7) Mehdi Tajvidi, Robert H. Falk, John C. Hermanson;" Effect of Natural Fibers on Thermal and Mechanical Properties of Natural Fiber Polypropylene Composites Studied by Dynamic Mechanical Analysis" Journal of Applied Polymer Science, Vol. 101, 4341–4349 (2006).

8) V. Ananda Rao, Alok Satapathy, S.C. Mishra," Polymer composites reinforced with short fibers obtained from poultry feathers "' National Institute of Technology, Rourkela 769008, India, December 12-14, 2007.

9) Yan Li, Chunjing Hu, Yehong Yu, "Interfacial studies of sisal fiber reinforced high density polyethylene (HDPE) composites", Composites Part. 2007 (in press).

Table (1) Density of difference natural fibers.

Fibers	White feather	Black feather	Egg shell	jute
Density $\left(\frac{g}{cm^3}\right)$	0.89	0.89	1.65	1.46

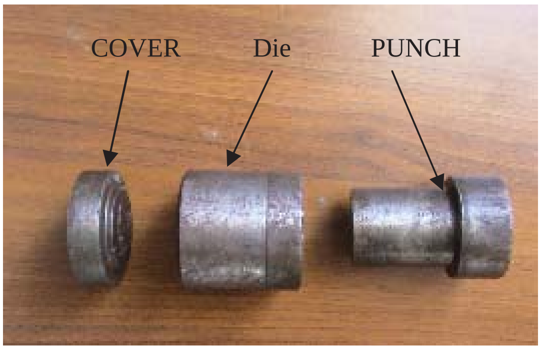
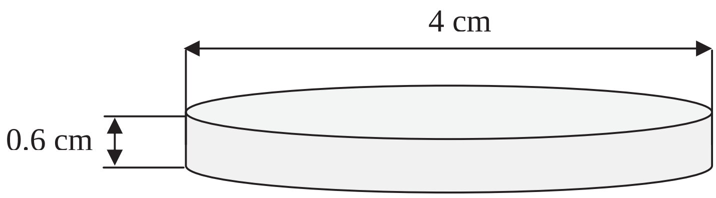


Figure (1) Iron mold for Lee's disc technique.



Figure(2) Sample dimensions of Lee's disc technique.

Figure (3) Natural composite disc.

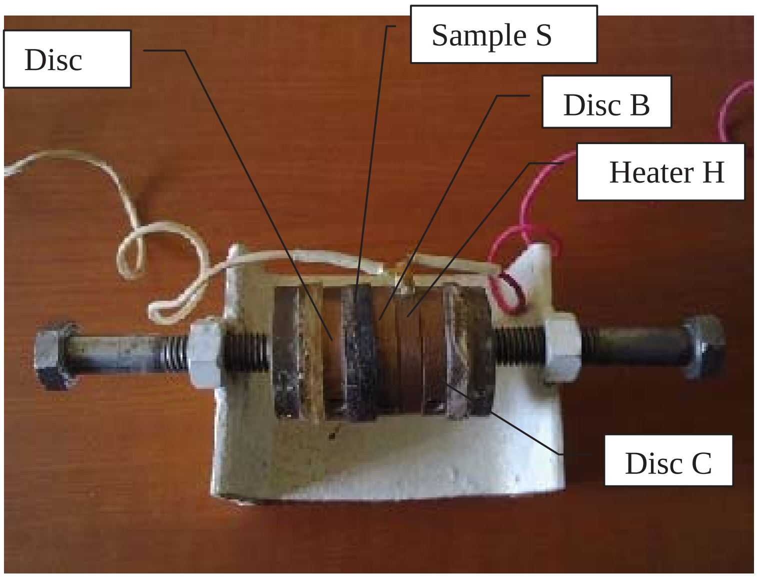


Figure (4) Lee's disc arrangement.

Figure (5) Natural composite plate.

Figure (6-a) Glass casting mold

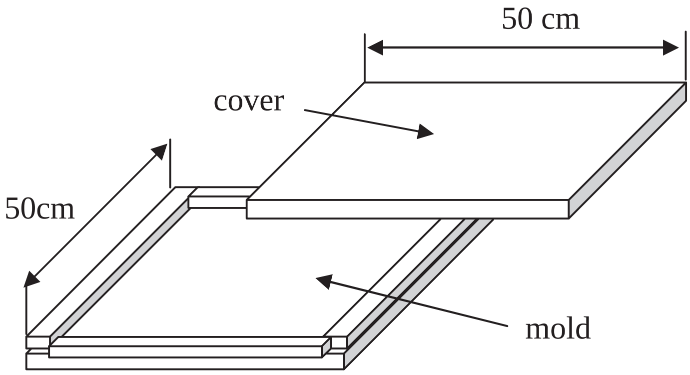


Figure (6-b) Schematic of glass mold.

Figure (7) Experimental Rigs.

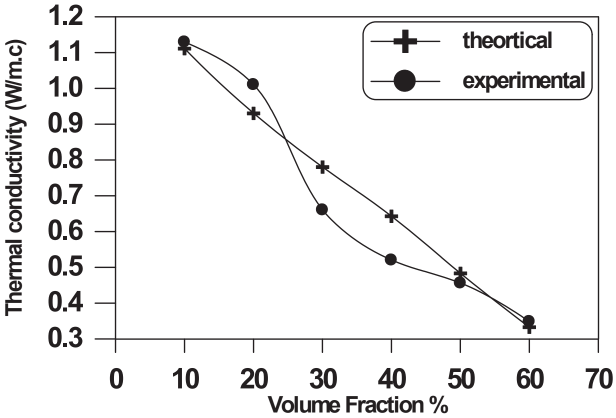


figure (8) Comparision between Theoritcal and experimental thermal conductivity (white feathers)

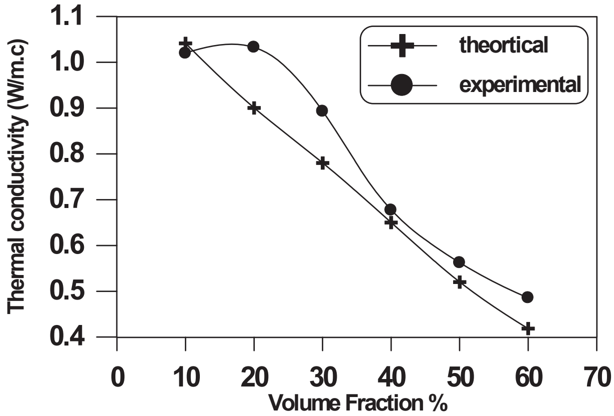


figure (9) Comparision between Theoritcal and experimental thermal conductivity (blackfeathers)

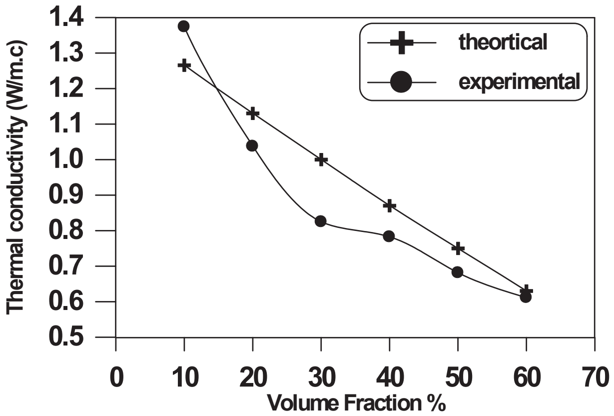


figure (10) Comparision between Theoritcal and experimental thermal conductivity (egg shell)

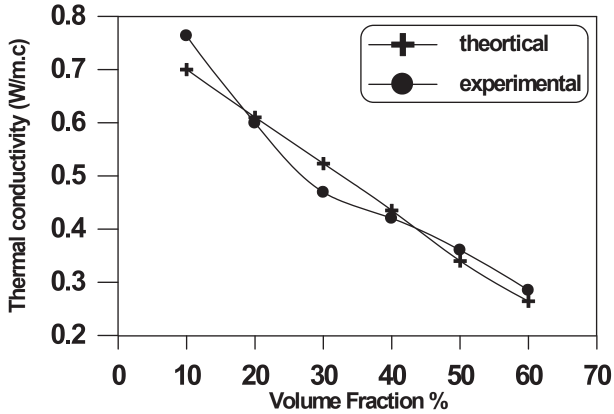


figure (11) Comparision between Theoritcal and experimental thermal conductivity (jute)

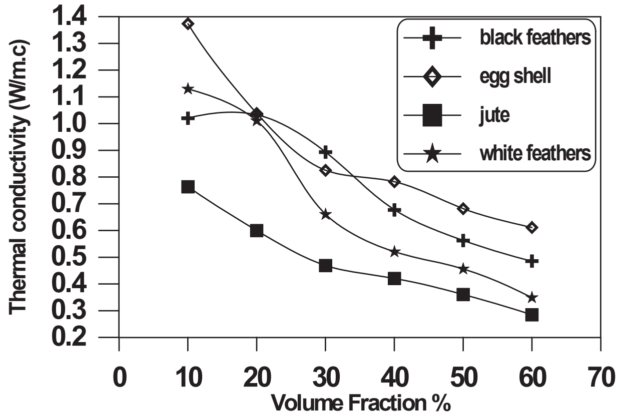


figure (12) Experimental Comparision between different types of natural composite materials

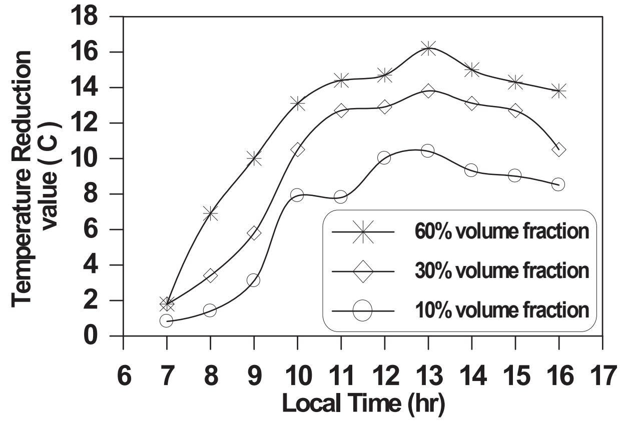


Figure (13) temperature reduction on bottom surface of the roof using composite white feather insulated (with air gap), different volume fraction

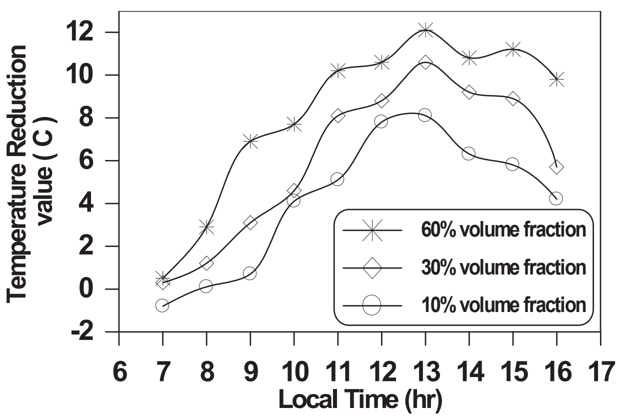


Figure (14) temperature reduction on bottom surface of the roof using composite white feather insulated (without air gap), different volume fraction

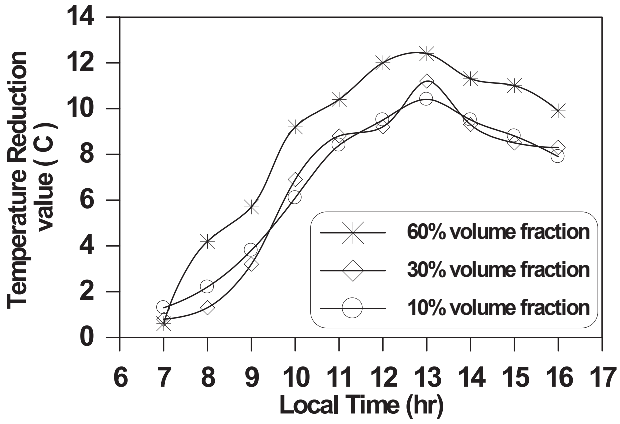


Figure (15) temperature reduction on bottom surface of the roof using composite black feather insulated (with air gap), different volume fraction

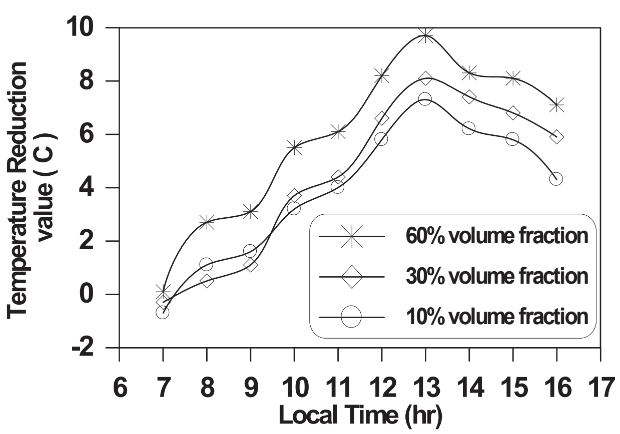


Figure (16) temperature reduction on bottom surface of the roof using composite black feather insulated (without air gap), different volume fraction

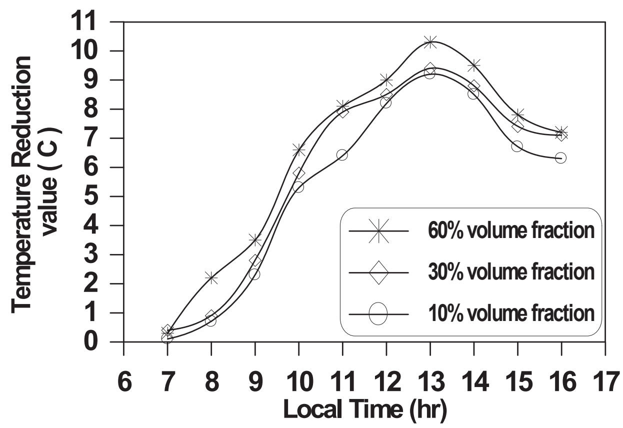


Figure (17) temperature reduction on bottom surface of the roof using composite egg shell insulated (with air gap), different volume fraction

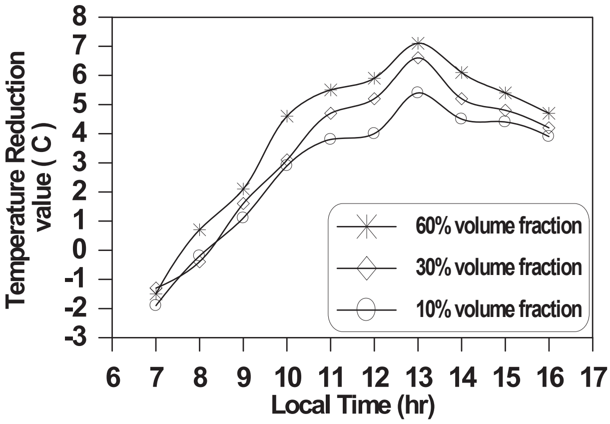


Figure (18) temperature reduction on bottom surface of the roof using composite egg shell insulated (without air gap), different volume fraction

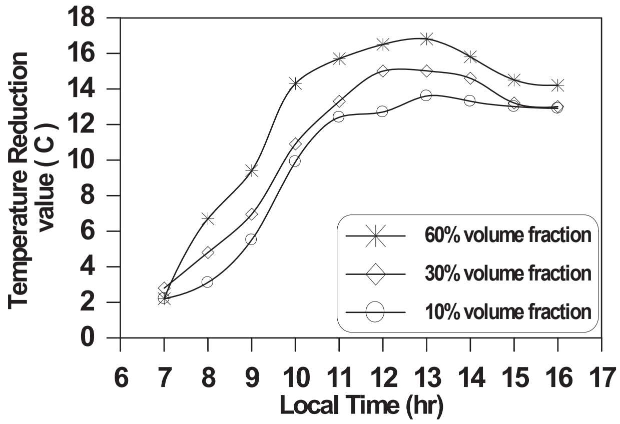


Figure (19) temperature reduction on bottom surface of the roof using composite Jute insulated (with air gap), different volume fraction

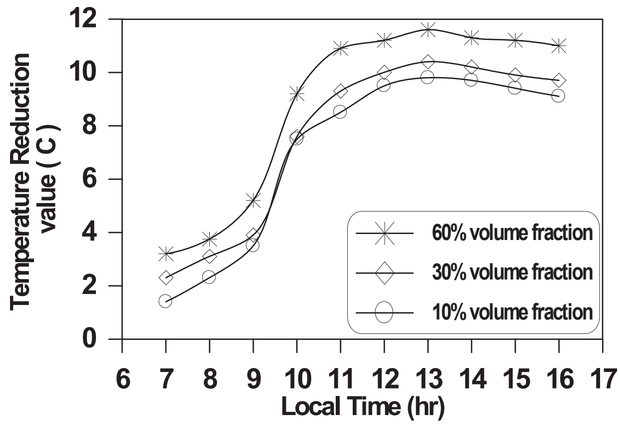


Figure (20) temperature reduction on bottom surface of the roof using composite Jute insulated (without air gap), different volume fraction

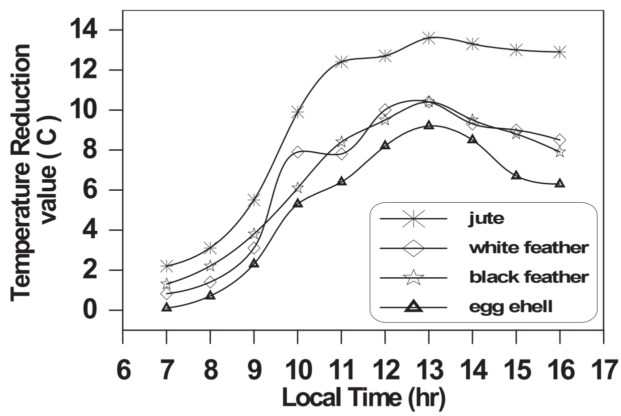


Figure (21) temperature reduction on bottom surface of the roof using different natural composite materials with air gap,10% volume fraction

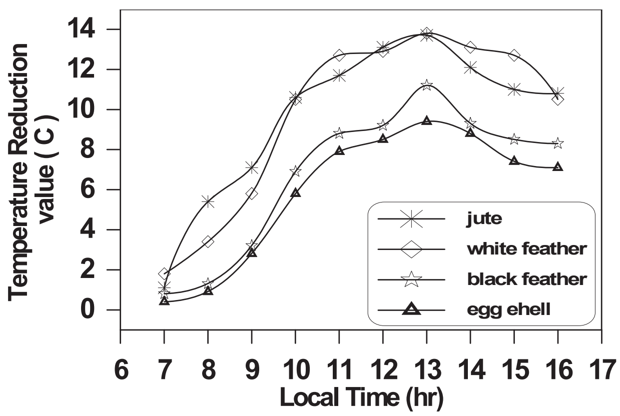


Figure (22) temperature reduction on bottom surface of the roof using different natural composite materials with air gap,30% volume fraction

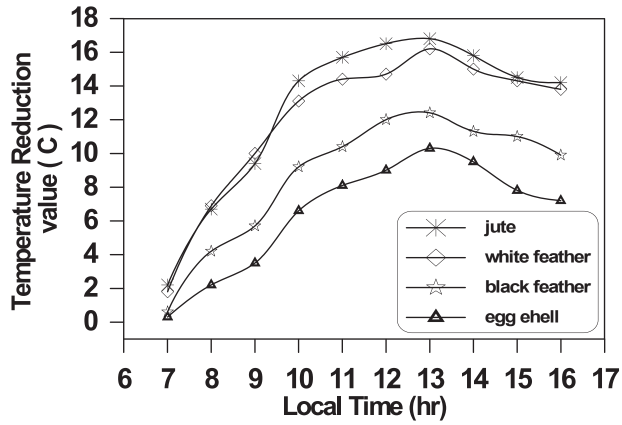


Figure (23) temperature reduction on bottom surface of the roof using different natural composite materials with air gap,60% volume fraction