Journal of Engineering and Development
www.jead.org
Vol. 19, No.05, September 2015
ISSN 1813-7822

Effect of Ultraviolet Radiation on Thermal Insulation of Natural Composite Materials

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(Received:9/11/2014 ; Accepted:21/1/2015)

Abstract

Thermal conductivity and performance of the natural composite materials as thermal insulator after exposure to ultraviolet radiation effect are investigated. Accelerated weathering chamber has been manufactured to investigate ultraviolet radiation effect on composite materials. The composite materials were prepared of polyester resin which reinforced with fiberglass, jute and eggshell powder. The experimental work has been divided into two parts. The first part studies the effect of ultraviolet radiation on the thermal conductivity of the composite materials with different volume fractions (20%, 40% and 60%) using Lee's disc method. The second part deals with manufacturing three test chambers (reference chamber, unaffected chamber and affected chamber) with dimensions of (50×50×50cm). These chambers are used to investigate the performance of composite materials, with specimens dimensions of (50×50cm) and 4mm thickness for volume fractions of (30% and 60%), as thermal insulators after weathering with ultraviolet radiation. Experimental results indicate that cladding the external wall of chamber by affected or unaffected composite materials gives lower temperature distribution inside the chamber along the day than without cladding. Thermal conductivity of fiberglass and eggshell composite materials with ultraviolet radiation effect is higher than that without ultraviolet radiation effect. While the thermal conductivity of jute composite material decreases after exposure to ultraviolet effect so that Jute composite material gives higher temperature reduction of (19%) comparing with fiberglass composite material (10%) and eggshell composite material (9%).

Keywords: *Thermal insulation; Composite material; Ultraviolet radiation; Thermal conductivity; Volume fraction.*

تأثير الأشعة فوق البنفسجية على العزل الحراري للمواد المركبة الطبيعية

الخلاصة

تم دراسه الموصلية الحرارية للمواد المركبة الطبيعيه وادائها كعوازل حراريه بعد التعرض للأشعة الفوق البنفسجيه. تم تصنيع جهاز تعجيل الظروف البيئية للتقصي عن تأثير الأشعة الفوق البنفسجية على المواد المركبة. حضرت المواد المركبه من راتنج البوليستر المعززب(الياف

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الزجاج ,الجوت,قشور البيض). الجزء العملي يقسم الى قسمين : الجزء الاول يدرس تأثير الاشعة الفوق البنفسجية على الموصلية الحرارية للمواد المركبة بكسر حجمي (٢٠٪، ٤٠٪، ٦٠٪) باستخدام طريقه قرص لي. الجزء الثاني يتضمن تصنيع ثلاث غرف اختبار(غرفه اختبار بدون عازل وغرفه اختبار مغلف جدارها بعينة غير معرضه للاشعه الفوق البنفسجيه واخرى تم اكساء جدارها بعينة معرضه لثاثير الاشعه الفوق البنفسجيه) بأبعاد (٥٠سم^3). غرف الاختبار تستخدم لدراسة اداء المواد المركبة بأبعاد (٥٠ × ٥٠سم) وبسمك ٤ملم بكسر حجمي(٣٠٪، ٦٠٪) كعوازل للحرارة بعد تعرضها لتأثيرالاشعه الفوق البنفسجيه. النتائج العملية تشير الى ان اكساء الجدار الخارجي لغرفه الاختبار بعينات متأثره وغير متأثره بالاشعه الفوق البنفسجيه تكون حرارتها الداخلية منخفضة مقارنه بغرفه الاختبار الغير مكسوة . الموصلية الحرارية للمادة المركبة المدعمة بألياف الزجاج وقشور البيض المتأثرة بالأشعة الفوق البنفسجية اعلى من قيمتها للعينات الغير متأثره بينما تنعكس النتيجة للمادة المركبة المدعمة بألياف الجوت لذلك اكبر نسبه انخفاض في درجات الحرارة داخل الغرفة تم الحصول عليها باستخدام المادة المركبة المدعمة بألياف الجوت بنسبه ١٩٪ مقارنه مع نسبة الانخفاض للمواد المركبة المدعمة بألياف الزجاج ١٠٪ والمدعمة بقشور البيض ٩٪

Nomenclature

Symbol	*Description*	*Units*
$d_{A, B, C}$	Thickness of the disk A, B, C	m
d_S	Thickness of the composite specimen	m
I	Electric current pass through heating coil	Amp
K	Thermal conductivity	W/m°C
R	Radius of the specimen	m
$T_{A, B, C}$	Temperature of the disk A, B, C	°C
V	Voltage across the terminal of heating coil	Volt

1. Introduction

Natural fibers are becoming potential alternatives for glass fiber reinforced composites in many applications. Usage of natural fibers like hemp and jute etc. instead of synthetic fibers leads to increase in specific properties like sound absorption and thermal insulation, where natural fiber is filled with cellulose material which acts as an insulator, and reduction in component's weight, **(Joshi et al., 2004)**.

The sun emits energy across the electromagnetic spectrum, but mainly in wavelength between 200 and 400 nm. Energy emitted as a function of wavelength is very similar to what is expected from a black body with a temperature of 6000 K , which is close to the sun's photosphere temperature, while the averaged energy flux density emitted at the photosphere is 6.2×107 W/m^2. The distribution of radiation depending on wavelength covers ranges called infrared (larger than 720 nm), visible (between 400 and 720 nm) and ultraviolet (UV).The ultraviolet radiation having wavelength in three bands in the range 200-400 nm, UVC corresponds to wavelength from 200-280 nm, UVB corresponds from 280 to 315 nm and UVA corresponds to wavelengths from 315 nm to the visible lower limit (400nm) **(Ali, 2007)**.

Degradation of polymer leading to physical property changes relative to the initially specified properties, all degradation generally involves changes to the molecular weight "molecular weight distribution" of the polymer and typical property change include "reduced ductility, color changes, cracking and general reduction in most other desirable physical properties.

Al-Zabiady (2002), studied the effect of temperature , humidity and ultraviolet on the properties of the natural rubber and the synthesis rubber in which crude natural and synthesis rubber sample are exposed to temperature range 40-80^{o}C for 2 -30 days and compared the mechanical and physical properties of exposed and unexposed samples. **Jones (2002)**, examined the effects of the ultraviolet radiation on the performance and properties of the polymer-based building products and used accelerated weathering techniques to assist in assessing the durability of building materials. It is envisaged that extended exposure of these materials will reveal some mechanical property differences due to photo degradation in the longer term. **Balkes** and **Ali** (2009), prepared a hybrid composite material contains a matrix which is epoxy resin reinforced by natural and fabricated fibers (kevlar fiber + woven and short glass fiber + palm fiber + metal fiber), the volume fraction for all hybrid composite material was 25%. Thermal tests were done by using Lee's disk to determine the thermal conductivity, after the samples were exposed for a period of time to (UV) (500, 1000 and 1500) hours, the results show that as the exposure time increased the thermal conductivity of samples decrease. **Emad (2010)**, prepared and studied epoxy-phenol system reinforcing with glass fibers with volume fraction (48%). The samples irradiated with ultraviolet radiation with wave length (320 nm) and irradiation energy (1.5 watt/ cm^2) for 50 hours. The thermal conductivity measured for all samples before and after irradiation with ultraviolet radiation. The results showed that the thermal conductivity increased for all samples after irradiation with ultraviolet radiation. **Andrej et al. (2011)**, analyzed the influence of simulated sun light radiation (xenon lamp) on physical properties of polypropylene nonwoven material, which is used for the production of agrotextiles. The research showed that the properties of row cover change when radiated with ultraviolet light, where thermal conductivity of nonwovens with exposure to xenon light increases. **Sarmad et al. (2013)**, prepared composite materials of unsaturated polyester resin reinforced by palm fiber extracted from different locations (Trunk, Petiole (bases leaflet date palm tree), Rachis and Panicle) of the palm tree in Iraq. The study included the effect of fiber location within the plant as well as the percentage of the volume fraction (0%, 10%, 20%, 30%, and 40%) on the thermal conductivity, where for the measurement of thermal conductivity the apparatus used was Lee's disk method. It was observed that the thermal conductivity for all these composite samples decreases with increasing the palm fibers content.

The result of published literature identified the necessity and importance of carrying out this study where increasing use of composites materials for various applications emphasizes its importance/significance in the thermal property analysis of an engineering system.

The nature of Iraqi climate which represents longevity the hot summer seasons, made almost the buildings depend on mechanical services to remove the cooling loads and ensure a suitable conditions of human activity within it. Therefore and for the importance of topic many architecture researches in Iraq focused on searching practical solutions that could reduce the consumption of energy in buildings. In this research, the strategy used to reduce the energy consumption is cladding external wall of buildings with new composite materials panels (fiberglass, jute and eggshell composite materials) subjected to ultraviolet radiation conditions.

3. Materials, Equipment and Experimental Procedures

3.1 Materials

Three types of reinforcements to prepare the composite materials (thermal insulation) were used. Two types are natural reinforcement (jute and eggshell powder) and the third type is fiberglass (Random fiberglass) which has a density (735kg/m^3).

The first type is jute which is the most important natural fiber which has a density (480 kg/m^3). The second type is eggshell which is a biomaterial containing 95% by weight of calcium carbonate in the form of calcite and 5% by weight of organic materials, such as (Al_2O_3, SiO_2, S, Cl, Cr_2O_3, MnO) **(Raul et al., 2007)**. The eggshell used in this work was brown eggshell and has a density (1370 kg/m^3), it was washed with water and sun dried to remove the membranes, grind to small particle sizes (75µm) using the grinding machine as shown in figure (1).

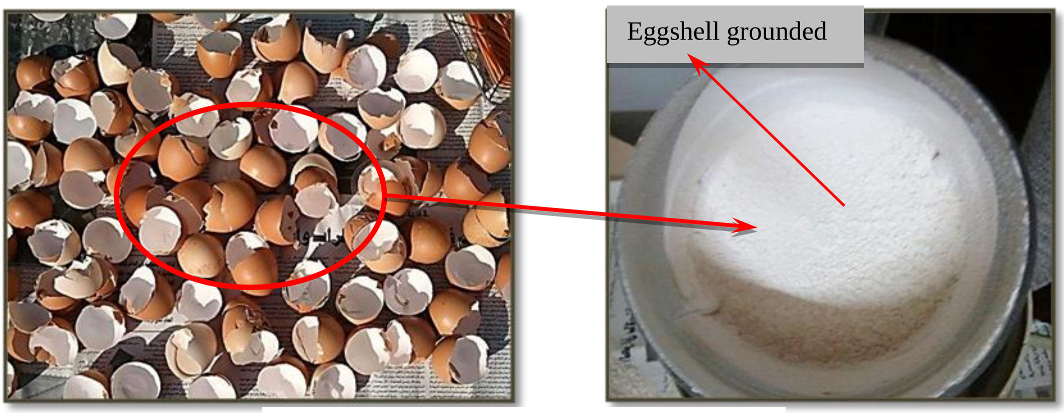

Figure (1) Eggshell powder.

These reinforcements are mixed with polyester resin which has a density of (1135 kg/m3) which is firstly mixed with a hardener.

3.2 Equipment

Thermal conductivity of specimens was measured by using Lee's disk method. The apparatus consists of four identical discs of (4cm) in diameter and (0.6cm) thickness, one of them includes an electrical heater inside it. The specimen (S) with (4cm) in diameter and (0.6cm) thickness was placed between the discs (A) and (B). The heater was sandwiched between (B) and (C) discs **(Duncan and Mark, 2001)**. Temperature of (A), (B) and (C) discs were measured using three digital thermometers, as shown in figure (2).

Heat was supplied with a D.C. power supply (V= 12 volt) as shown in figure (3) and the current (I) was measured (0.5 Amp). The heat transfers from the heater to the next two disks then the third disk across the samples.

The thermal conductivity calculated from the equation: **(Emad, 2010)**.

$$K = \frac{e\,[T_A + 2/r\,\{da + (1/4)\,ds\}\,T_A + (1/2r)\,dsT_B]}{(T_B - T_A)/ds} \qquad \dots (1)$$

The heat flow (e) per unit area and through the unit time (second) is calculated by the following formula:

$$e = I\,V / [\pi r^2\,(T_A+T_B) + 2\pi r\,\{d_A T_A + 1/2\,ds\,(T_A+T_B) + d_B T_B + dcTc\}] \qquad \dots (2)$$

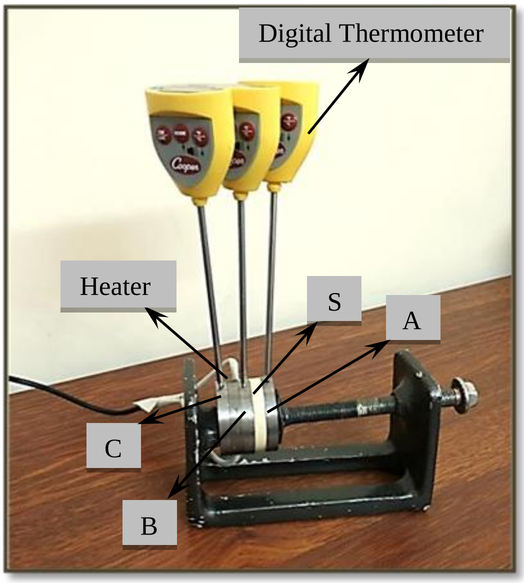

Figure (2) Lee's disc apparatus.

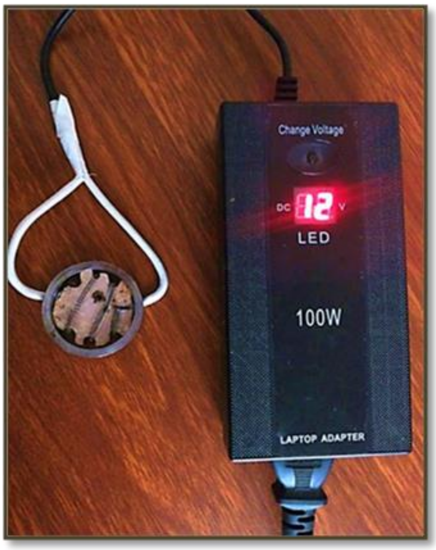

Figure (3) Heater and DC power supply.

3.3 Experimental Procedures

The experimental procedure started with preparation of small and big size composite material.

Small specimens with three volume fraction (20%, 40% and 60%) for each type of reinforcement which is used to measure thermal conductivity by using Lee's disc technique and big specimens with two volume fractions (30% and 60%) which will be used to study its behavior as an insulator and to study the effect of UV radiation on its insulation ability.

3.3.1 Small Size Specimen Preparation (Lee's disc specimen)

Cast-iron mold is used to prepare the specimen which was used for thermal conductivity measurement using Lee's disc method in circular shape with dimension (4×0.6 cm). The next steps were followed in mold process:

- Firstly the mold was cleaned from dirt.
- The mold is smeared with wax to prevent the sample from adhesion in the mold.
- One layer of fiber glass or jute reinforcement is applied.
- Polyester resin which is first mixed with a hardener by (2%) of the polyester resin is poured.
- Number of reinforcement layers and the quantity of polyester risen will added according to the desired volume fraction.
- After that this sample is left to dry.

For eggshell reinforcement, its powder mixed with polyester resin (which is first mixes with a hardener) according to the desired volume fraction (20%, 40% and 60%). Then the mixture was poured into the mold and left it to dry at room temperature until the sample ready to use, as shown in figure (4).

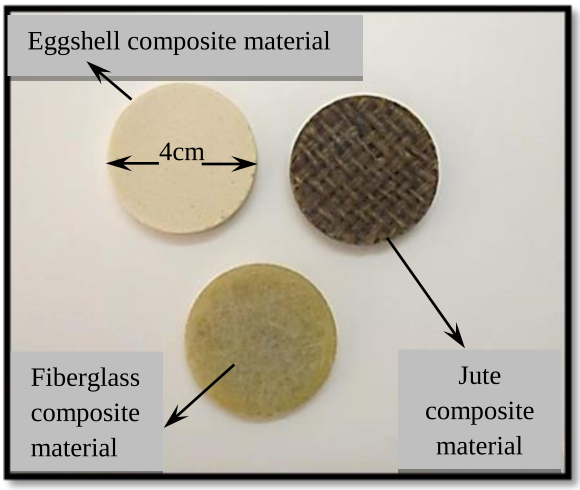

Figure (4) Specimens for thermal conductivity measurement.

3.3.2 Big Size Specimen Preparation

The composite plates used in this work consist from reinforcement (fiberglass, jute and eggshell) and matrix (polyester resin with hardener 2%), without adding the hardener the polyester will stay liquid. To fabricate the composite plate of size (50×50cm) with 4mm thickness as shown in figure (5), the mixture (reinforcement and matrix) is cast in mold which made of glass. This operation are done in a closed space and used buffer material to avoid direct contact between the specimen and the mold surface .After molding the sample insulating cover is used and apply distributed load to avoid keeping any air gap trapped in the sample**.**

Figure (5) Specimens of jute, eggshell and fiberglass composite material.

3.3.3 Test Chambers Manufacturing

To investigate the effect of composite materials as thermal insulation; three chambers were built to measure the temperature distribution inside them throughout daytime when the thermal insulation is installed. The three chambers are similar in construction and dimensions. Their dimensions are (50×50×50cm). The first chamber is used as a reference to indicate the internal temperatures of the chamber without the thermal insulation and to compare it with the second and third chambers. Composite materials with and without environmental effect were fixed on the second and third chambers respectively, as shown in figure (6). The chamber consists of:

1- Iron structure.

2- The structure of three walls, roof and floor are made of (6cm thickness) cork, the reason is to eliminate the effect of temperature gain throughout them.

3- The fourth wall made of concrete and its dimension is (50×50×3cm) to simulate the wall construction in Iraqi buildings.

Thermocouples types (k) were used to determine the temperatures of the test chambers. One thermocouple was used in each test chamber center as shown in figure (7). The temperature was measured and listed hourly in all days of experimental work. The thermal insulator is fixed on the external surface of concrete wall with direct contact between the concrete wall and the insulator. Fan was used to make a ventilation space and to circulate the air inside the chamber as shown in figure (8).

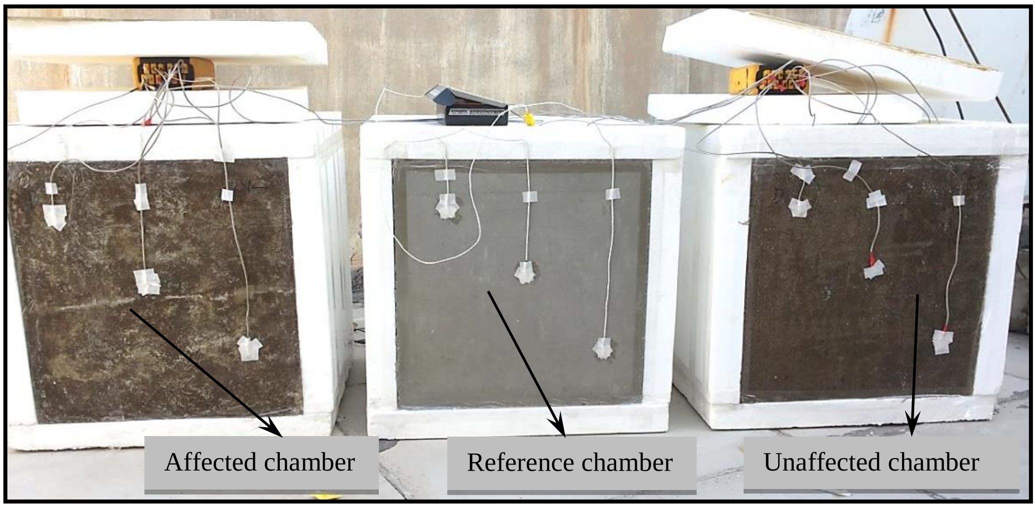

Figure (6) Test chambers with arrangement of thermocouples on samples.

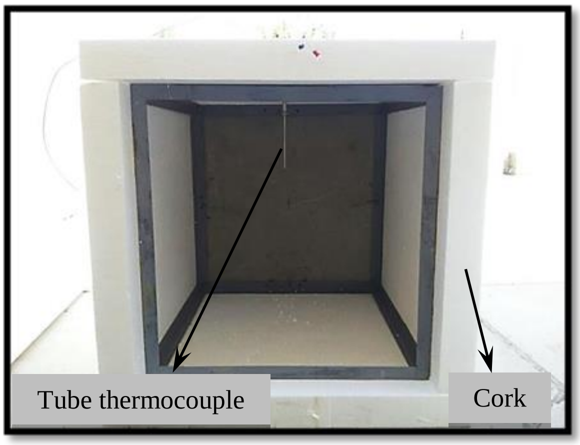

Figure (7) Tube thermocouple location.

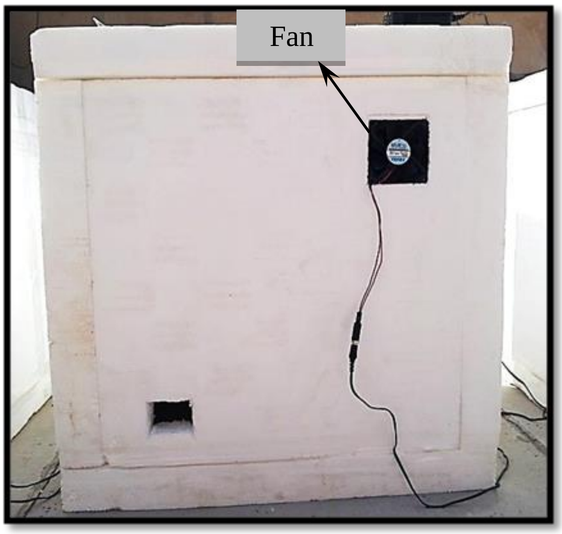

Figure (8) Ventilation spaces.

3.3.4 Accelerated Weathering Chamber

The prediction of the effect of ultraviolet radiation on composite materials by natural weathering exposure is too slow. Therefore, the accelerated weathering chamber was manufactured in the present study, as shown in figure (9), where artificial weathering of products is often used to provide information about the effects of the environmental condition. There are many accelerated methods to simulate ultraviolet radiation but the more popular accelerated UV techniques are fluorescent ultraviolet tube and the xenon arc lamp. The short wavelength portion of sunlight is responsible for much of the degradation of materials and fluorescent tubes simulate this portion very well **(Jones, 2002)** which used in this study. Figure (9) shows the arrangement of the fluorescent tubes used to generate the ultraviolet radiation. Fluorescent tubes placed inside the chamber as five stages, which has (20W power) and wavelength in the range 200-280 nm as measure in the University of Al-Mustansiriya.

Figure (9) Arrangement of UV fluorescent tube.

4. Results and Discussion

Experimental results represent the thermal conductivity of different type of composite materials for different volume fraction before and after exposure to ultraviolet radiation with accelerated weathering chamber for (100 days). The effects of different types of composite materials (thermal insulation) and the volume fraction with and without UV radiation on the temperature reduction are also investigated.

4.1 Effect of Volume Fraction and Types of Composite Materials on Thermal Conductivity

Figure (10) shows the relation between thermal conductivity of composite materials (fiberglass, jute and eggshell) and volume fraction. The experimental results proved that the value of the thermal conductivity of the specimens was higher when the reinforcement is fiberglass than that when the reinforcements are eggshell or jute. Also the experimental results indicated that the thermal conductivity increases with the increasing of the volume fraction that is because increase of the volume fraction means increase the volume of reinforcement compared with polyester resin which has (reinforcement) higher thermal conductivity than polyester resin. Minimum value was (0.0897 W/m°C) for eggshell composite materials at volume fraction 20% and maximum value was (0.225 W/m°C) for fiberglass composite materials at volume fraction 60%.

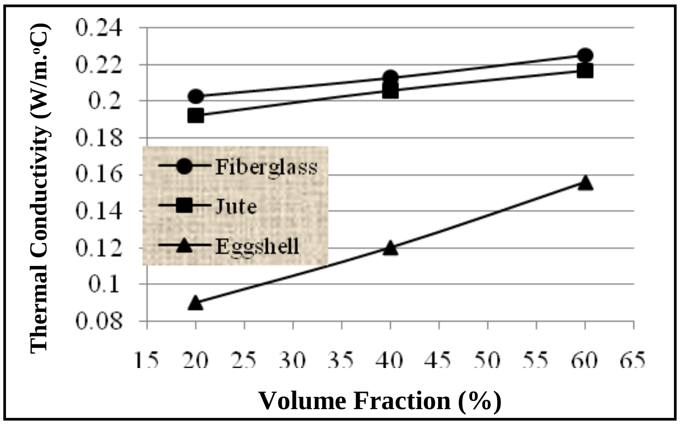

Figure (10) The effect of volume fraction on thermal conductivity of composite materials.

4.2 Effect of Ultraviolet Radiation on Thermal Conductivity

After weathering with UV radiation for 100 days, the results of thermal conductivity are shown in figures (11), (12) and (13).

Figure (11) represents the relation between the thermal conductivity of fiber glass composite material and exposure time of ultraviolet radiation for different volume fractions

(20%, 40%, and 60%). It is obvious that, the thermal conductivity of all volume fractions increases in comparison with the thermal conductivity before exposing to UV radiation, this result may be attributed to that: UV radiation causes increase of crosslinking for the polymer chains as a result the molecular weight of the polymer chains increased which leads to increase the path to transfer photons.

Figure (12) shows the process of change in the values of thermal conductivity of jute composite materials after exposure to ultraviolet (UV) for different time periods (17, 42, 70, 85, 100) days, where it is noted that the value of the thermal conductivity decreases with the increase in the duration of exposure to UV radiation for all volume fractions, as a result of weaken and destroying of the cross linkage that depending on the nature of the material.

Figure (13) gives the same relation of figure (12) but for eggshell composite material. Experimental results clearly indicate that the ultraviolet radiation exposure time increase causes thermal conductivity increase for all volume fractions.

Thermal conductivity of fiberglass, eggshell and jute composite materials with exposure time to ultraviolet radiation for (20%, 40% and 60%) volume fractions is shown in figures (14, 15, and 16) respectively. The experimental results that have been found indicate that,

- The jute composite materials give less value of thermal conductivity.
- The minimum value of thermal conductivity (0.0897 W/m°C) is achieved for eggshell composite materials at volume fraction of 20% before UV radiation exposure.
- The maximum value of thermal conductivity (0.225 W/m°C) is achieved for fiber glass composite material at volume fraction of 60% before UV radiation exposure.
- After 100 days of exposure to UV radiation the minimum value of thermal conductivity was achieved (0.143 W/m°C) for jute composite materials at volume fraction 20% and maximum value was achieved (0.329 W/m°C) for egg shell composite material at volume fraction 60%.

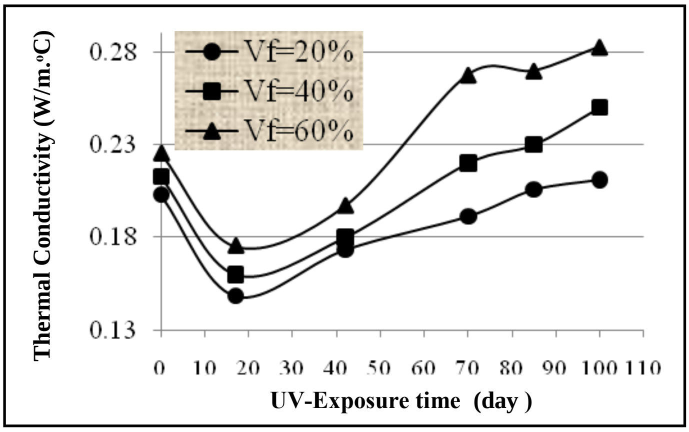

Figure (11) Thermal conductivity of fiberglass composite material with exposure time of ultraviolet radiation.

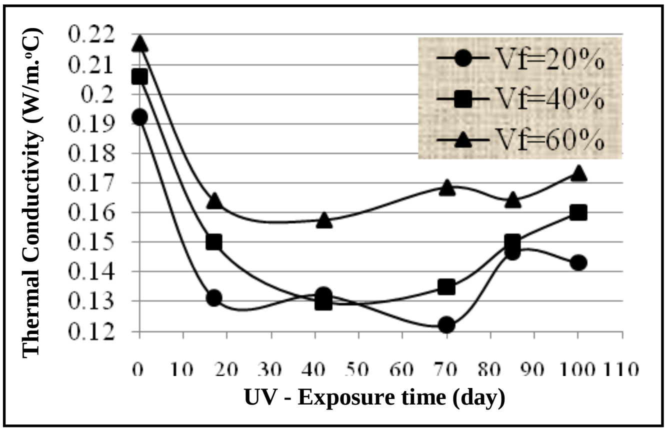

Figure (12) Thermal conductivity of jute composite materials with exposure time of ultraviolet radiation.

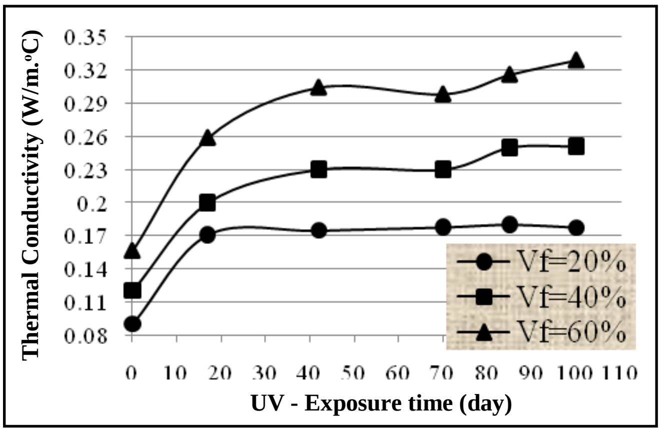

Figure (13) Thermal conductivity of eggshell composite material with exposure time of ultraviolet radiation.

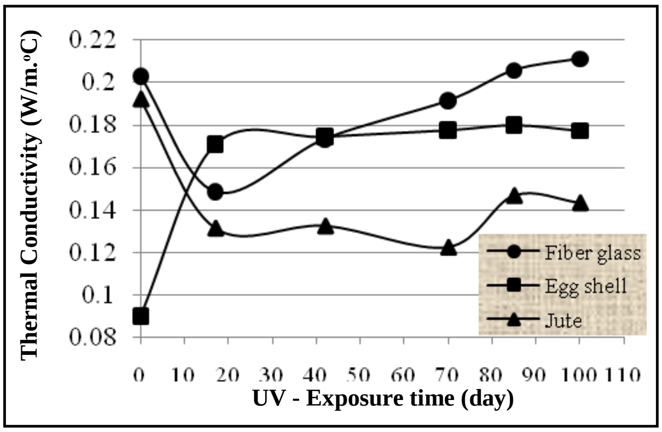

Figure (14) Thermal conductivity of composite materials with volume fraction (20%) with exposure time to ultraviolet radiation.

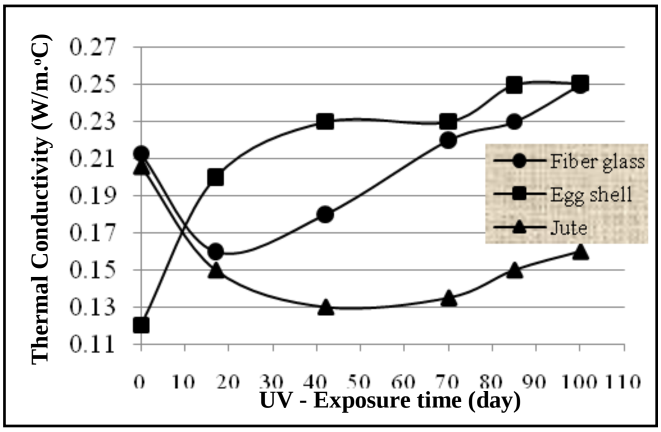

Figure (15) Thermal conductivity of composite materials with volume fraction (40%) with exposure time to ultraviolet radiation.

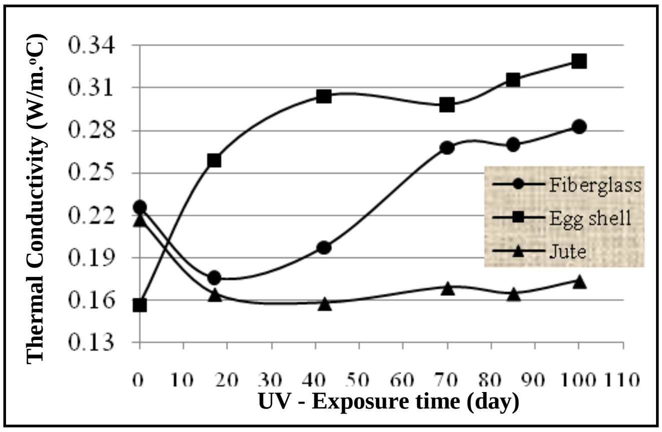

Figure (16) Thermal conductivity of composite materials with volume fraction (60%) with exposure time to ultraviolet radiation.

4.3 Effect of Ultraviolet Radiation on Thermal Insulation

Investigating the effectiveness of composite materials as thermal insulator, after weathering with UV radiation for (100 days) inside accelerated weathering chamber, requires the internal temperature inside the test chamber which cladding by it during the day. Three chambers are used, the first one is reference chamber (its wall without composite material), second chamber is unaffected chamber (its wall covers by unaffected sample) and last chamber is affected chamber (its wall covers by affected sample). The daily temperature distribution was shown in figures below.

Figures (17) to (22) disclose the daily temperature distribution for affected and unaffected different composite materials throughout daytime. It was accomplished for (30% and 60%) volume fraction. It can be seen from these figures that,

- Daily temperature distribution for affected (exposure to ultraviolet radiation) fiber glass and eggshell composite materials are higher than that of unaffected samples due to increase of thermal conductivity after exposing to UV radiation.
- Daily temperature distribution of affected jute composite material is lower than that of unaffected sample due to decrease of thermal conductivity after exposed to UV radiation.
- The temperature reduction of jute composite material for (Vf =30%) is (18.99%) which is the highest value of temperature reduction.
- The temperature reduction increases with volume fraction decrease.

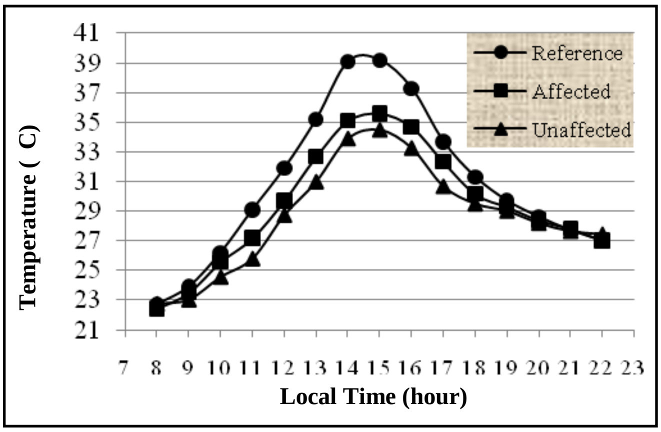

Figure (17) Daily temperature distribution for unaffected and affected fiber glass composite material with UV radiation at 30% Vf.

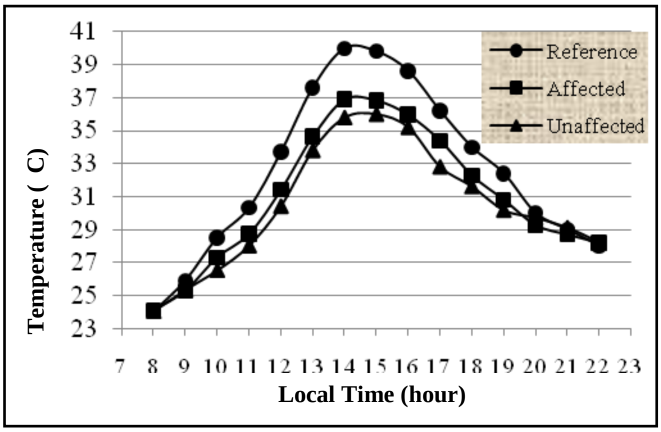

Figure (18) Daily temperature distribution for unaffected and affected fiber glass composite material with UV radiation at 60% Vf.

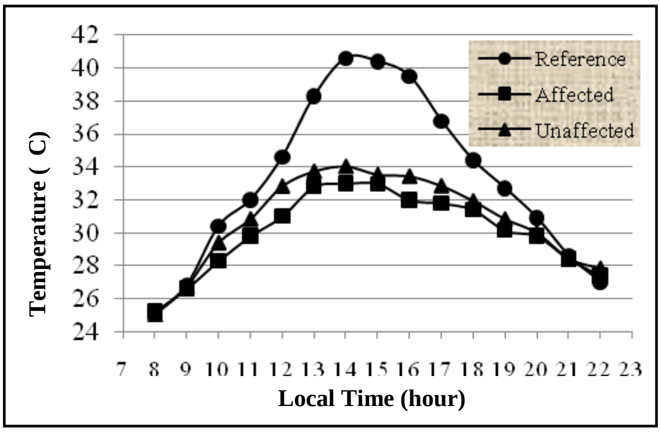

Figure (19) Daily temperature distribution for unaffected and affected jute composite material with UV radiation at 30% Vf.

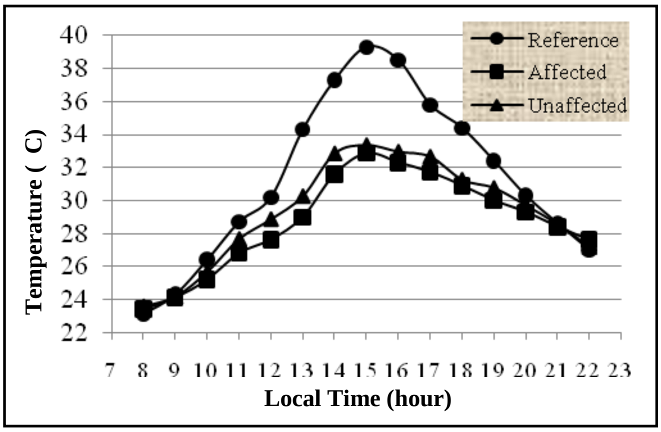

Figure (20) Daily temperature distribution for unaffected and affected jute composite material with UV radiation at 60% Vf.

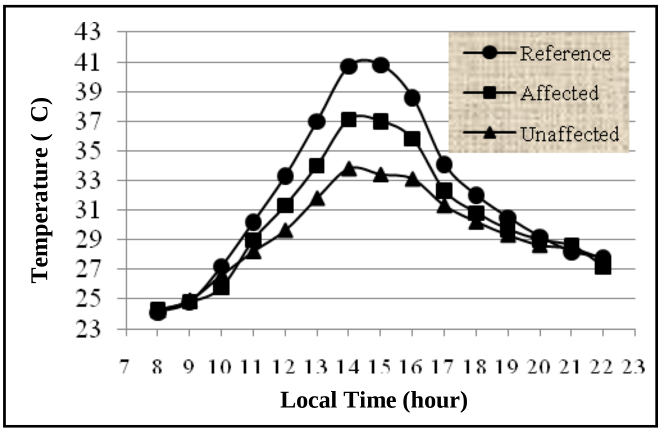

Figure (21) Daily temperature distribution for unaffected and affected eggshell composite material with UV radiation at 30% Vf.

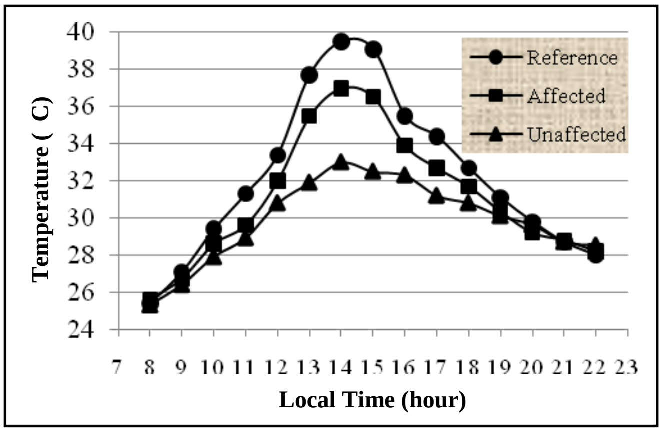

Figure (22) Daily temperature distribution for unaffected and affected eggshell composite material with UV radiation at 60% Vf.

5. Conclusions

The most important conclusions resulting from present study will be outlined in the following points:

1- The increase in volume fraction will lead to an increase of the thermal conductivity for fiberglass, jute and eggshell composite materials.

2- Jute and eggshell composite materials have less thermal conductivity than fiberglass composite material before exposure to ultraviolet radiation.

3- Thermal conductivity without ultraviolet radiation effect is lower than the thermal conductivity with ultraviolet radiation effect for fiberglass and eggshell composite materials. While the thermal conductivity of jute composite material decreases after exposure to ultraviolet radiation.

4- The temperature reduction inside the test chamber is increased by cladding the external wall of test chamber with affected and unaffected composite materials.

5- Volume fraction increase leads to thermal conductivity increase of affected and unaffected specimens for fiberglass, jute and egg shell composite materials, which leads to increase of the daily temperature distribution inside the test chamber.

6- Jute composite materials gives higher reduction in temperature of 19% inside the chamber during the day comparing with fiberglass composite material (10%) and eggshell composite material (9%) after exposure to ultraviolet radiation.

6. References

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