International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-2, Issue-8, August 2016
ISSN: 2395-3470
www.ijseas.com

An experimental and analytical study to show the Effect of the reinforced carbon fiber percentages on the epoxy thermal conductivity and the heatsink performance

Thamer Khalif Salem[1,2] **Raaid Rashad. Jassem,**[1,2] **Saad Sami. Farhan**[2]
Thamer_khalif@yahoo.com **Raaid.rashad@yahoo.com** **Saadsami_77@yahoo.com**

[1]Ozyegin University, School of Engineering, Cekmekoy, Istanbul, Turkey

[2]Department of Mechanical Engineering, College of Engineering, University of Tikrit,
Tikrit, Iraq

ABSTRACT

The main purpose of this paper is that showing the enhancement of thermal conductivity of the epoxy with many percentages of carbon fiber into it. In addition to pure epoxy and pure carbon fiber, three percentages of carbon fiber are used in this study, which are 20, 40, and 60%, respectively. All of these samples are tested at different values of applied powers (input power) (10, 25, 40, 55, and 70 W). A comparison between pure epoxy, pure carbon fiber and the composites that involve all these percentages is done. In addition, the study involves the effect of these simples on the performances of both Aluminum and cooper heat sinks.

It is shown from the results that increasing in fiber carbon percentage leads to increasing in thermal conductivity of composite, heat sink junction temperature, overall heat sink efficiency, and density of composite. The increasing in overall heat sink efficiency leads to decrease the height of heat sink, and consequently decreasing its cost. For instance at 70 W power input, increasing the fiber carbon percentage(from 0 to 100%) for each material of heat sink, leads to decrease the average fin length by 48% ,decrease the manufacturing cost by 47%, increase in junction temperature by 65 %, and increase fin efficiency by 2.5 %.

Key Words: thermal conductivity**,** fiber carbon**,** Epoxy, Al and Cu heat sink, Forced convection

NOMENCLATURE

A	surface contact area, m^2
Cp	specific heat, kj/kg.k
d	diameter, m
h	heat transfer cofficient , W/m^2.^{o}C
I	current amper,Amp
l	length of heat transfer path,m
L	characteristic length, m
p	perimeter, m
q	Power device fitted to the conductivity, W
R	thermal resistance, ^{o}C/W
ΔT	temperature difference,^{o}C
V	Potential difference (voltage), volt

Greek Symbols

ε	effectiviness,-
k	thermal conductivity, W/m.K
$\dot{m}$	mass flow rate, kg/s
ρ	density, kg/m^3
η	efficiency, %

Subscripts

a	ambient
b	base fin
c	cross section
f	fin
s	surface
spd	spreading
u	un fin
CFRP	carbon fiber reinforced polymer

Introduction:

These days in most our devices there are undesirable heat should be removed or dissipated to the surrounding in order to cool them. Heat sinks are the most known devices that are used for this purpose. All companies try to improve the performance of them in order to get enhancement in the devices efficiencies. In addition to Heatsinks design, the materials that usually put between the hot surfaces and heatsinks have significant effects on the heatsinks performance figure (1). These materials which usually known TIM (Thermal interface material), are usually produced from two or more components to achieve the improvement in their physical and chemical properties [1].

One of these properties is thermal conductivity (k) that plays roll in increasing the performance of Heatsink. Composite material that is produced from adding carbon fiber to the Epoxy is one of these materials. Producing composite materials or thermal interface materials have been studied by many researchers.

Kalaprasad *et al.* [2], 2000, analyzed and presented the thermal conductivity and thermal diffusivity of sisal-reinforced polyethylene, glass reinforced polyethylene and sisal/glass hybrid fiber reinforced polyethylene composites by the means of TPS method. The TPS technique is based on the three-dimensional heat flow inside a sample which can be regarded as an infinite medium by limiting the total time of transient recording.

Composites present high thermal anisotropy in a long-fiber and perpendicular-to-fiber direction. Based on **Hwan-Boh Shim et al [3],2002**, the thermal conductivity ratio between these two direction can be varied between 40~130. In practice, the in-plane direction of fiber-composite often aligns with the along-fiber direction, and through-thickness direction is often the perpendicular-to-fiber direction. In many applications, both in-plane heat spreading and through-thickness heat removal are important for effective heat dissipation.

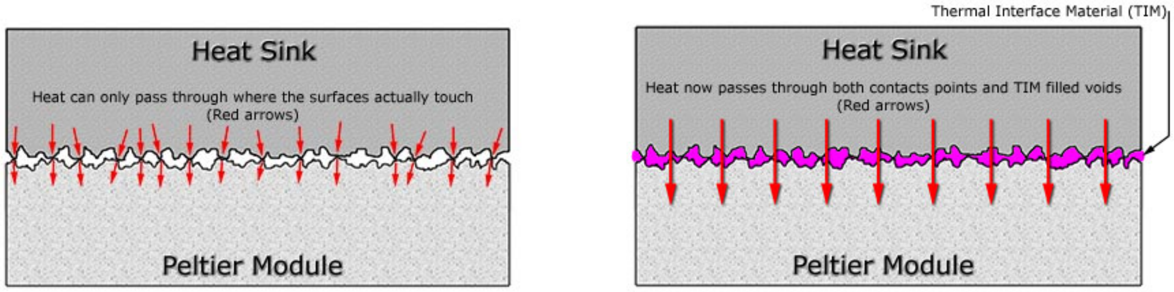
Three volumetric percentages of vapor-grown carbon fiber-reinforced polypropylene composites is studied by **Kuriger, 2002[4]**. Thermal conductivity with a lase flash instrument in longitudinal and transverse directions for 9, 17 and 23% volumetric percentages are measured and their values are 2.09, 2.75, and 5.38 W/m.K for longitudinal and 2.42, 2.47, and 2.49 W/m.K for the transverse direction, respectively, While 0.24 W/m.K is the thermal conductivity of unfilled polypropylene.

Thermal conductivities in longitudinal and transverse directions of a CFRP unidirectional composite are evaluated experimentally by **Shinji O and etals, 2005 [5]**. Laser flash method is employed to measure thermal conductivity. The steady state and transient heat transfer simulations are performed by using FEM to predict composite thermal conductivities. An effect of fiber volume fraction on the thermal conductivity is discussed for both experimentally and analytically studies. A hybrid matrix material is employed in order to enhance the thermal conductivity of a CFRP. In the hybrid matrix, Alumina particles are embedded in the epoxy resin. The study discussed the effects of fiber volume fraction and the hybridization of matrix on composite thermal conductivity.

Also **Adnan A. and etals,2009[6]** studied the Thermal and electrical conductivity of an insulating polymer can be achieved by dispersing conducting particles (e.g., metal, carbon black) in the polymer. The resulting materials are referred to as conducting polymer composites. Electrical and thermal properties of epoxy carbon black composites were studied in this work. The weight fraction of the carbon blacks ranged from 0.0 up to 20 wt % with the epoxy resin. By discharging a high voltage through the composite it was found that the resistivity of the composite decreased. Epoxy-carbon black composites show significant differences from the neat epoxy resin measured in the frequency range. Conductivity percolation threshold was found when carbon blacks is added in the range of 1 and 2 wt%. It was found that the epoxy/ carbon black composites have better thermal properties than the neat epoxy.

Moreover, the relation between the thermal conductivity of polymer composites and the realistic size of GNP fillers within the polymer composites has been studied by **Hyun Su Kim, 2016**[7]. The result showed that there was a reverse relation between the size and thickness of GNPs and the matrix-bonded interface. Also the thermal conductivity is improved by up to 121% depending on the filler size; the highest bulk and in-plane thermal conductivity values of the composites filled with 20 wt% GNPs were 1.8 and 7.3 W/m.K, respectively. Simultaneously, the bulk and in-plane thermal conductivity values increased by 650 and 2.942%, respectively, comparing to the thermal conductivity of the polymer matrix used.

In this study the TIM is produced practically with different percentages of carbon fiber into Epoxy (0, 20, 40, 60 & 100% C.F) In order to enhance thermal conductivity of it. The thermal conductivity of these samples is calculated using specific device figure (1). These values of thermal conductivity are used in computational program (Icepak-Ansys) in order to make simulation that explains their effect on the Heatsink performance. In addition to Heatsink dimension, the cost of two components will be estimated according to their prices in table (1) that shows the thermosphysical properties of all composites, heat sink material and the price of each them [8].



Contact without any TIM **Contact using a TIM**

Figure (1) shows the interface TIM with heat sink.

Table (1) the thermosphysical properties of all composites, heat sink material and the price [8]

MATERIAL	CONDUCTIVITY w/m.k	DENSITY g/cm^3	price
Carbon Fiber (FC)	21-180	**1.78**	$22 USD per kg
Epoxy (EP)	0.5-1.5	1.11-**1.4**	2.8 USD *per kg*
20%FC+80%EP	-	1.4079	3.184 USD *per kg*
40%FC+60%EP	-	1.4152	3.568 USD *per kg*
60%FC+40%EP	-	1.4228	3.952 USD *per kg*
AL pure	237	2.712	2.0286 USD *per kg*
Cu pure	400	8.94	6.724 USD *per kg*

Composite material:

Experimental Work

Due to the development of alloys and their use in all fields of life, our consisting to carry out a study to determine the effect of fiber carbon to epoxy on the thermal conductivity of the composite and heat sink efficiency.

A device for Measuring Thermal Conductivity

The device used to measure the thermal conductivity Consists of two pieces of copper placed inside two pieces of Teflon as a buffer. As well as an electric heater, be controlled by thermal regulator (thermostat), and the amount of heat transmitted from the heater to the alloy is placed between two pieces of copper can be controlled by the voltage regulator. And using water to cool the end of the sample to ensure the heat transfer in one direction is the axis of the cylinder, and measured temperatures by eight thermocouples type (T), placed three of them before the sample and the other three after the sample and two on the sample surface after the hole on the Teflon insulation and the user, to ensure that thermal losses. As shown in Figure (2), that shows us a photograph of the user's device. Method of conducting the experiments to measure the heat conductivity:

1. Put the sample between the poles of copper and Teflon insulated composed.

2. Operation of the electrical heater, placed under a single polar copper and control electrical power within organized by the use of five different voltages, to calculate the rate of thermal conductivity of the composed accurately.

3. Measure the power entering the heater, the voltage and current by measuring placed in the device which was measured to be equal to (10, 25, 40, 55 &70 watt).

4- The dimensions of cylindrical sample is (L=2.5 cm & d= 2 cm)

5. After the arrival of the electric heater to the required level and stability of temperatures after reaching the state of stability for the time period (30 minutes) take readings of the twin themes on the surface of the sample only, and is due not to our use of bisexual six placed before and after the sample is a different metal alloy being placed between two metal made of copper and thus a difference in thermal conductivity caused by an error in the measurements.

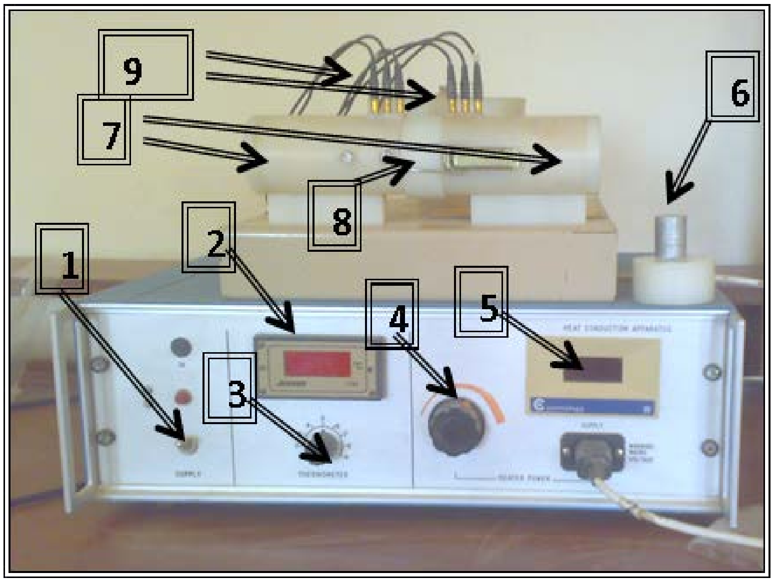


Figure (2) a photograph of the device for measuring thermal conductivity describes the used devices in the research: 1- Power key. 2- A digital scale with temperature. 3 - Control of the thermocouples. 4 - Voltage regulator. 5 - Measure of power. 6 - Test sample with Teflon. 7 - Teflon isolated copper electrodes. 8 - Place the test sample. 9 – Thermocouples.

Tests Procedure:

1. Setup the apparatus as shown in the figure using the steel sample.
2. Measure the thickness and diameter of the sample and note down the values. Lubricate the contact surfaces with a good thermal-conducting lubricant or grease to minimize thermal contact resistance (it is better for any surface irregularities NOT to be filled with poorly conducting air). Switch on the instrument.

3. Before turning heating or cooling, check all temperature readings (at all points 1-8). If the apparatus is in equilibrium with the room air, all temperature sensors should indicate the same temperature except for the measurement errors. Record the readings and use any consistent discrepancy for corresponding correction later.
4. Connect the tube to the water supply, which connects the cooler end of the apparatus to be cooled. Make sure the outlet water goes to the drain. This may be already done for you.
5. Open the water supply so that enough water flows through the cooler.
6. Switch on the heater so that the power supplied is about 15 W. An optimum heating power should be found so that the relative lost to the surroundings by radiation and convection is minimized. Even though we have covered the apparatus with plastic insulation, it is not a perfect thermal insulator, so some fraction of the heat supplied will be lost and the error in the calculation will occur.
7. Hook the temperature sensor connector to any one of the temperature sensors on the hot side (number 1, 2, and 3 on the Figure) and wait until the system reaches a steady state. Steady state means the temperature does not change with respect to time. For example, if the temperature does not change by more than 0.1^{o} C we may assume the steady state is reached.
8. Record the readings for all the six locations (1, 2, and 3 on the hot side and 6, 7, and 8 on the cold side, see the Figure (3) [9].

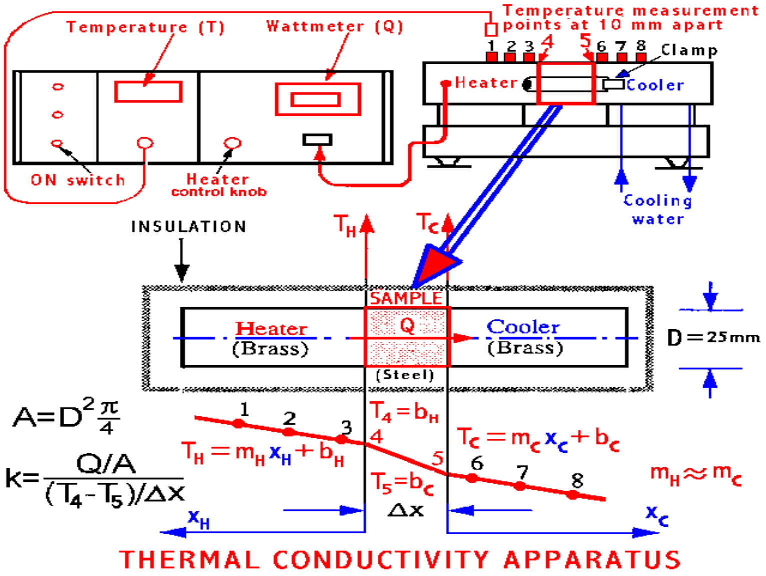


Figure (3) shows the schematic diagram of a procedure
to measure the thermal conductivity of materials

Experimental Calculation

Accounts of Thermal Conductivity

Heat form of energy transition, moving from the area with a high temperature to the region of low temperature in several images, namely, (conduction, convection, and radiation), and heat was transferred to one or more of these images. The transfer of heat conduction, has created the world Fourier law observed from which the heat transmitted through the middle of a directly proportional with temperature difference and the space perpendicular to the direction of heat flow (A), and inversely with the length of the distance traveled by the temperature[10].

$$q \propto A \frac{\Delta T}{\Delta x} \quad (1)$$

And that the constant of proportionality is the thermal conductivity (k), which is a property of properties of the center carrier, indicates its ability to deliver heat [11].

$$q = kA \frac{\Delta T}{\Delta x} \quad (2)$$

To calculate the value of the constant (k), we rearrange equation (2) to get the new formula, namely [12].

$$k = \frac{q \times \Delta x}{A \times \Delta T} \quad (3)$$

Where: $A = \pi \times d^2/4$

The rate of heat protractor (q) can be calculated as follows:- transmitted through the metal equal to rate of heat gained by the electric heater [13].

$$\mathrm{q} = \mathrm{I} \times \mathrm{V} \quad (4)$$

Thermal Resistance:

Thermal resistance can be simply calculated by knowing the intended bond thickness, thermal conductivity of the interface material, and surface contact area between component and substrate. Figure (1) shows the TIM with heat sink. The thermal resistance formula is shown below [14]:

$$R = {}^{l}/_{k} \times A \quad (5)$$

Heat sink

Heat sinks are devices capable of removing heat from a system which they are in direct contact by exchanging the extracted heat with another fluid or its surroundings. This is normally achieved by increasing the surface area significantly while also increasing the heat transfer coefficient. Today heat sinks are usually applied to the thermal management of electronic devices and systems. Heat sink work on the principle of conducting heat from the base where it is being generated and convicting it to another fluid or its surroundings. Therefore, it involves both conduction and convection heat transfer. In this study, the heat sink type was used is the cross pin fin heat sink with two different materials Aluminum and copper [15].

Analytical analysis:-

Heat sink performance

In this case, the maximum heat transfer from the fin can be expressed as [16]:

$$Q_{finmax} = A_{fin}h\left(T_b - T_f\right) \tag{6}$$

Total heat fluxed is that from the un-finned surface plus the heat flux from the [17]:

$$Q_T = Q_u + Q_{fin} \tag{7}$$

The heat transfer rate without the fin from area *A* to the surrounding fluid is[18]

$$Q_u = A_u h\left(T_b - T_f\right) \tag{8}$$

The heat transfer rate with very long-fin is:

$$Q_{fin} = (hpkAc)^{1/2}\left(T_b - T_f\right)tanh(mL) = \eta_{fin} * Q_{fin,max} \tag{9}$$

Since $m = \left(\frac{hP}{kAc}\right)^{1/2}$

The fin effectiveness can be determined by this relation:

$$\varepsilon_{fin} = \frac{Q_{fin}}{hA_b\left(T_b - T_f\right)} \tag{10}$$

Then overall effectiveness is:

$$\varepsilon_{fin,overall} = \frac{Q_{total,fin}}{Q_{total,no\ fin}} = \frac{Q_u + Q_{fin}}{hA_b\left(T_b - T_f\right)} \tag{11}$$

Fin efficiency:-

$$\eta_{fin} = \frac{Q_f}{hA_{fin,max}\left(T_b - T_f\right)} = \frac{1}{mL} \tag{12}$$

The temperature is increased to T_2. The heat, Q, transferred from the heat sink [19]:-

$$Q = hA(T_s - T_a) \tag{13}$$

The heat transfer from the heat sink is absorbed by air

$$Q_{air} = \dot{m}C_p(T_2 - T_1) \tag{14}$$

The thermal resistance of the fin can be calculated as:

$$R_{fin} = \frac{1}{\eta_f A_{fin} h_{fin}} \tag{15}$$

The thermal resistance of the base material is given by:

$$R_{base} = \frac{1}{A_{base} h_{base}} \quad (16)$$

The combined thermal resistance of fin and base material can be expressed by:

$$R_f = \frac{1}{\frac{1}{R_{fin}} + \frac{1}{R_{base}}} \quad (17)$$

R_f explains the conductive part of the thermal resistance in a heat sink. The convective contribution can be simplified as:

$$R_{flow} = \frac{1}{\dot{m} C_p} \quad (18)$$

One could consider the spreading resistance as well by definition:

$$R_{spd} = \frac{T_s - T_a}{Q} \quad (19)$$

The contribution of the spreading resistance to the overall device temperature rise is significant if the footprint of a heat sink is much larger than the size of the heat source, considering this, the total thermal resistance of a heat sink can be defined:

$$R_t = R_f + R_{flow} + R_{spd} \quad (20)$$

Results and discussion:-

Figure (4) shows the relation between the weight percentage of Carbon fiber adding to Epoxy and the density property of the composite material. The results show that the composite density increasing as a result of increasing the weight percentage of Carbon fiber from (0, 20,40,60 & 100% C.F), because the carbon fiber has higher density than Epoxy.

Figure (5) represents the relation between the input power and the thermal conductivity property of the composite material for (0,20,40,60 & 100% C.F) . The results show that the composite thermal conductivity increasing as a result of increasing of the input power for all composites when adding carbon fiber to the Epoxy, because the carbon fiber has higher thermal conductivity than Epoxy and it is a good metal to enhance thermal conductivity of these composites.

Heat sink junction base temperature (T_{jb}) affects by increasing the input power in **Figure (6)**. The results shows T_{jb} increase as increasing the input power for all composites (0,20,40,60 & 100% C.F), that's because the Carbon fiber has lesser thermal resistance than Epoxy metals. Also, lower thermal resistance of composites due to increasing T_{jb} see equation (20).

Figure (7) shows the relation between the weight percentage of Carbon fiber adding to Epoxy and the T_{jb} of the composite material. The results show that the T_{jb} increases as a result of increasing the weight percentage of Carbon fiber from (0, 20, 40, 60 & 100% C.F), because the carbon fiber has lower thermal resistance than Epoxy. Also, T_{jb} increases as increasing the input power because the proportional relation between them.

The relationship between the Aluminum heat sink fin length and the weight percentage of Carbon fiber adding to Epoxy is shown in **Figure (8)**. The results shows Fin length decrease as increasing the weight percentage of Carbon fiber by (0,20,40,60 & 100% C.F), that's because increasing the total thermal resistance of Aluminum heat sink with the composites metal at constant power input. Also the Fin length decrease with increasing the input power from (10 to 70 watt).

Figure (9) shows the relationship between the copper heat sink fin length and the percentage of Carbon fiber adding to the Epoxy. When increasing the weight percentage of Carbon fiber by (0,20,40,60 & 100% C.F) and the input power from (10 to 70 watt), caused the Fin length will be decreases, that's because increasing the total thermal resistance of copper heat sink with the composites metal at constant power input. Also the Fin length of the copper heat sink is lower than the Fin length of the copper heat sink, because the thermal conductivity of copper is higher than Aluminum.

Figures (10&11) show the relationship between the weight percentage of Carbon fiber adding to the Epoxy and the total cost of Aluminum and copper heat sinks respectively. The results show the total cost of heat sinks decrease with increasing the percentage of C.F for all composites, because of decreasing the fin length of the two types of heat sinks. Also the total costs of heat sinks decreases with increasing the power input, but the copper heat sinks has higher total cost than Aluminum heat sink because the copper material cost is expensive than Aluminum material.

The effectiveness of heat sink with the percentages of Carbon fiber is shown in **Figure (12)**. The results shows the heat sink effectiveness decreasing as increasing the increasing the weight percentage of Carbon fiber by (0,20,40,60 & 100% C.F), that's because increasing the T_{jb} and the relationship between T_{jb} and the effectiveness of heat sink is inversely proportional.

Figure (13) represents the relation between the percentage of Carbon fiber adding to the Epoxy and the thermal resistance of the composite material. The results show that the composite thermal resistance decrease as a result of increasing the composite material for (0,20,40,60 & 100% C.F), because the carbon fiber has higher thermal conductivity than Epoxy. Also the thermal resistance decrease with increasing the power input from (10 to 70 watt).

The relationship between the weight percentage of Carbon fiber adding to the Epoxy and the overall efficiency of Aluminum and copper heat sinks respectively are shown in **Figures (14&15)** . The results show the overall efficiency of heat sinks increase with increasing the percentage of C.F for all composites, because the total heat dissipation with fins is larger than total heat dissipation with no fin. Also the overall efficiency of heat sinks increase with increasing the power input, but the copper heat sinks has higher overall efficiency than Aluminum heat sink because the copper material conductivity is bigger than Aluminum material.

The numerical simulation is done by using Icepack program to know the effect of carbon fiber percentage on the temperature contour at input power 70 watts for each material of heat sink, see

Figures (16&17). These figures show the junction temperature increases by increasing the percentage of carbon fiber and it decreases by changed the heat sink material from Aluminum to Copper. Also, the temperature difference of Aluminum heat sink is higher than Copper heat sink for each percentage of carbon fiber. That difference is normal because the thermal conductivity of Copper is larger than thermal conductivity of Aluminum, which means lower thermal resistance.

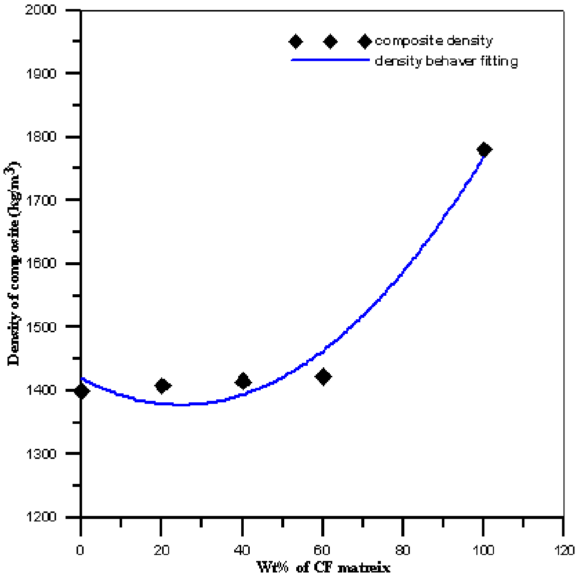


Fig (4) The Variation of the composite density with weight percentage of carbon fiber.

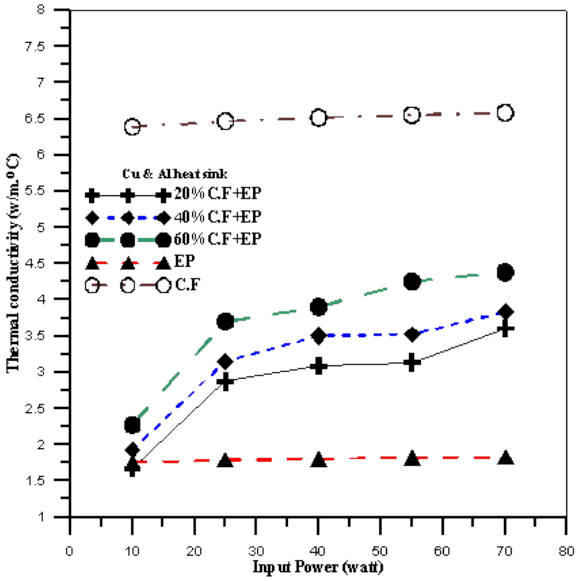


Fig (5) Variation of the composite thermal conductivity with input power at different C.F. percentages.

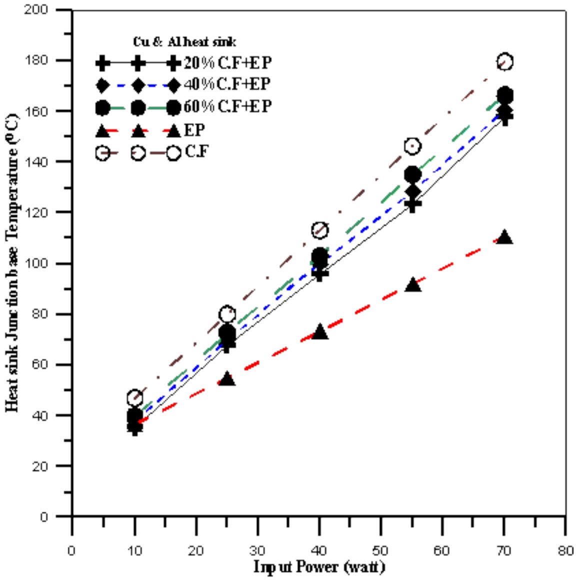


Fig (6) Variation of the Tjb with input power at different C.F. percentages.

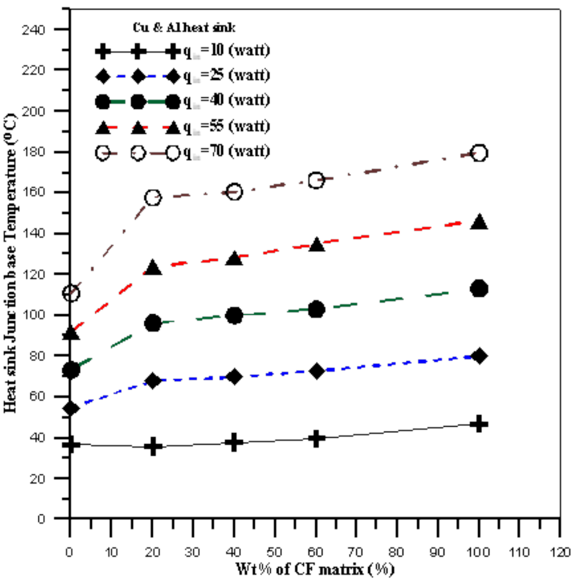


Fig (7) The Variation of the Tjb with weight percentage of carbon fiber, at different input power.

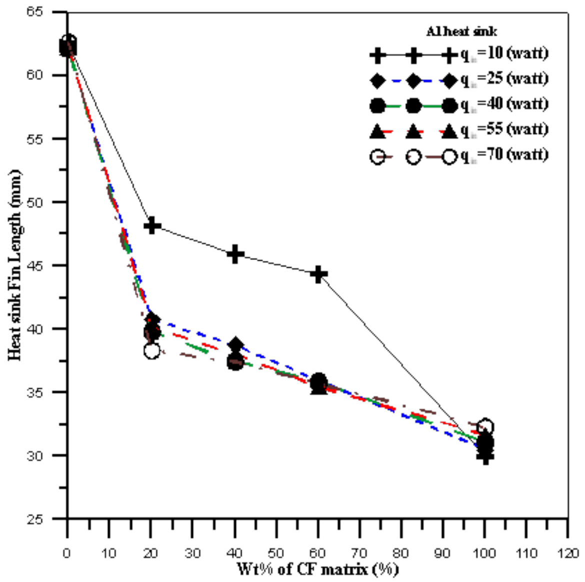


Fig (8) The Variation of the Al-Fin Length with weight percentage of carbon fiber, at different input power.

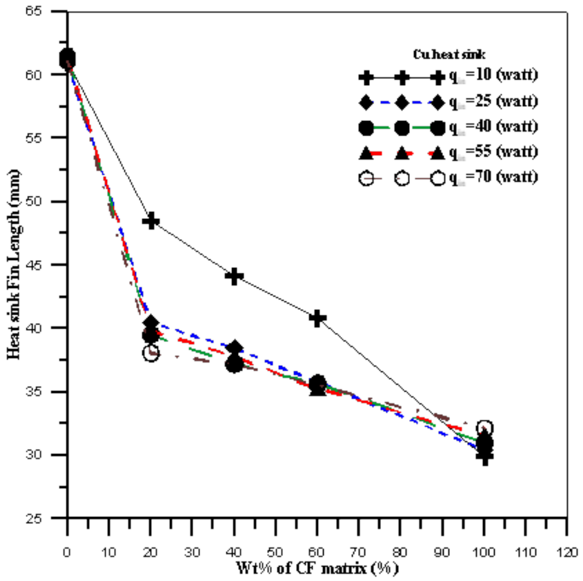


Fig (9) Variation of the Cu-Fin Length with weight percentage of carbon fiber, at different input power.

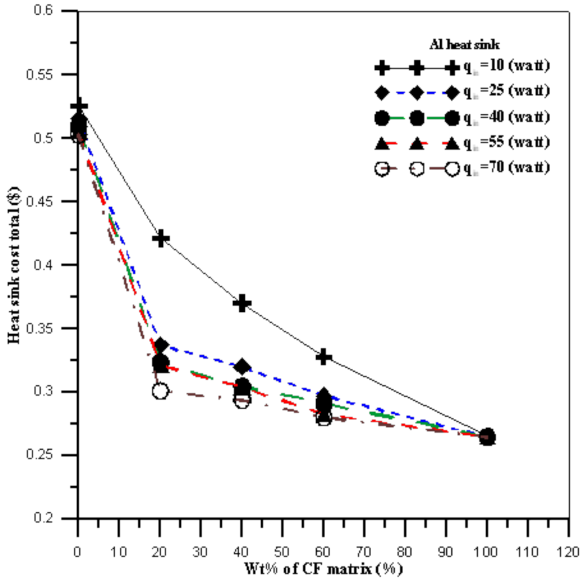


Fig (10) Variation of the Al-cost total with weight percentage of carbon fiber, at different input power.

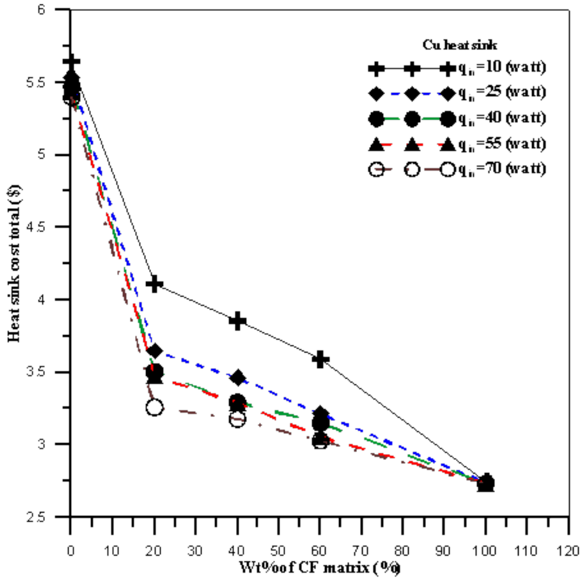


Fig (11) Variation of the Cu-cost total with weight percentage of carbon fiber, at different input power.

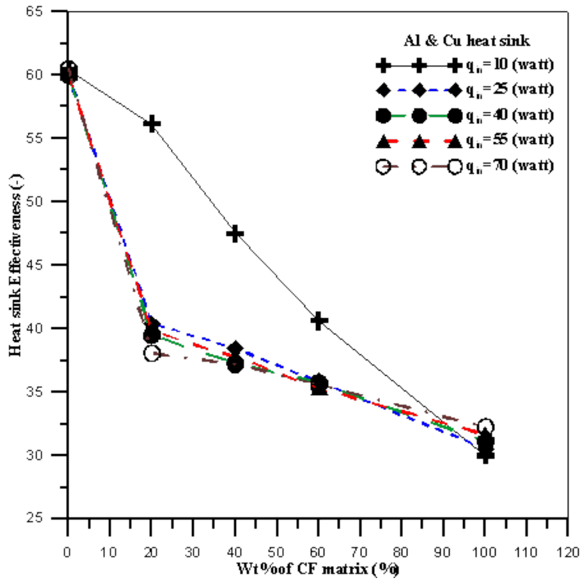


Fig (12) Variation of the H.S. Effectiveness with weight percentage of carbon fiber, at different input power.

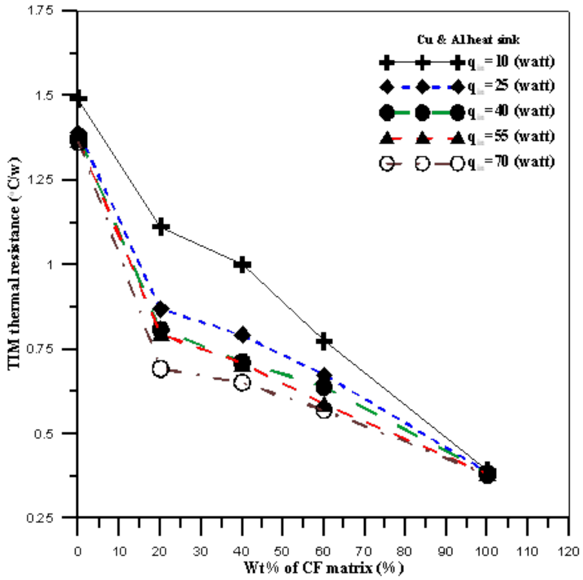


Fig (13) Variation of the composite thermal Resistance with the carbon fiber percentage, at different input power.

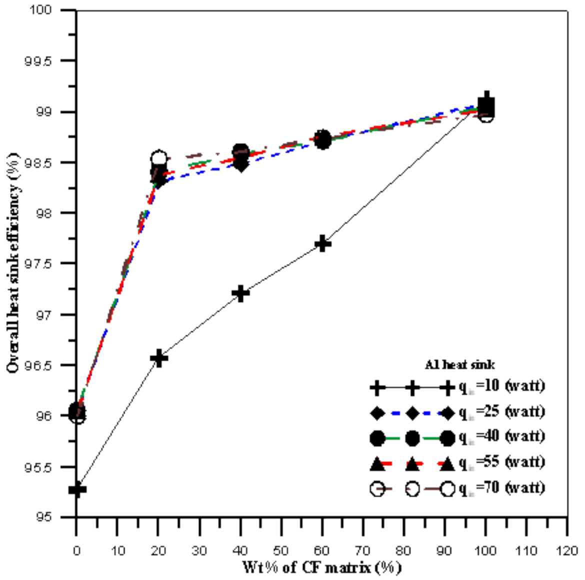


Fig (14) Variation of the Al-H.S. overall efficiency with the carbon fiber percentage, at different input power.

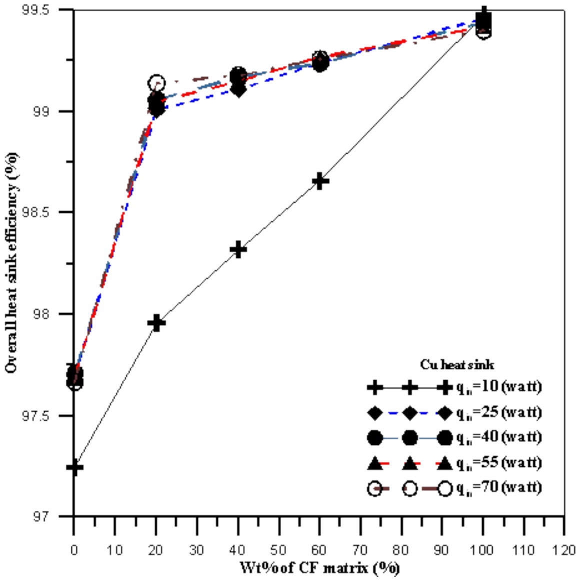
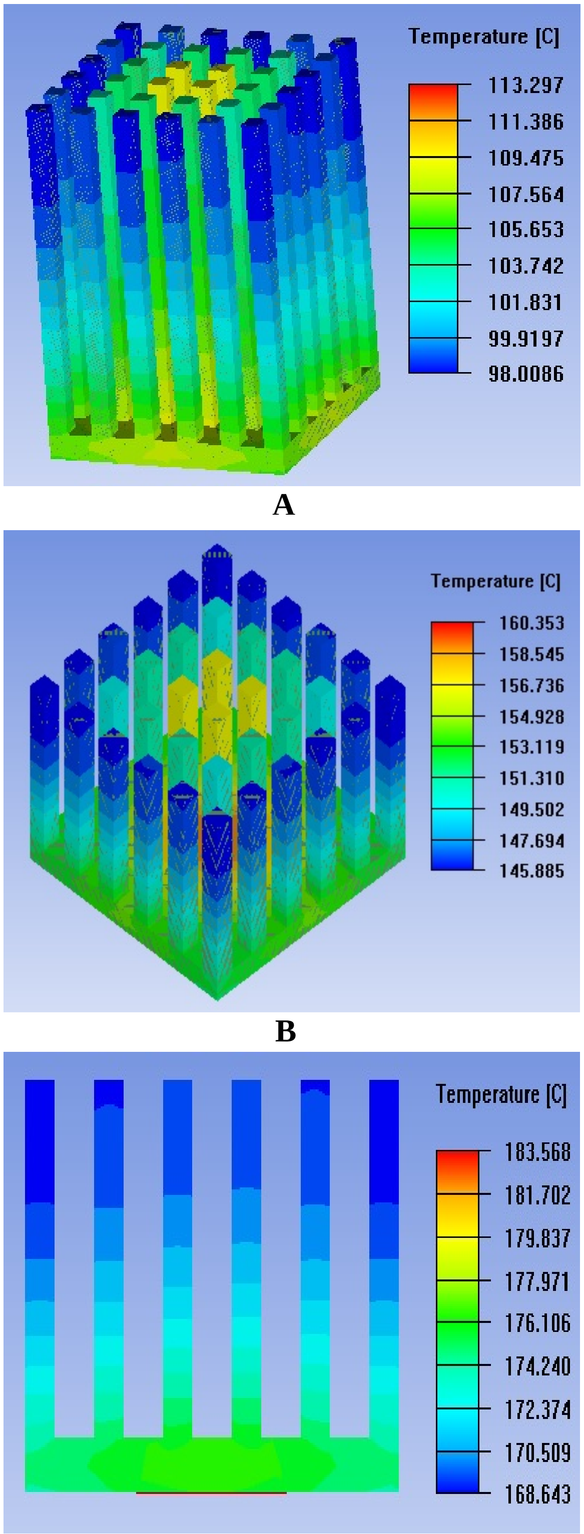


Fig (15) Variation of the Cu-H.S. overall efficiency with the carbon fiber percentage, at different input power.

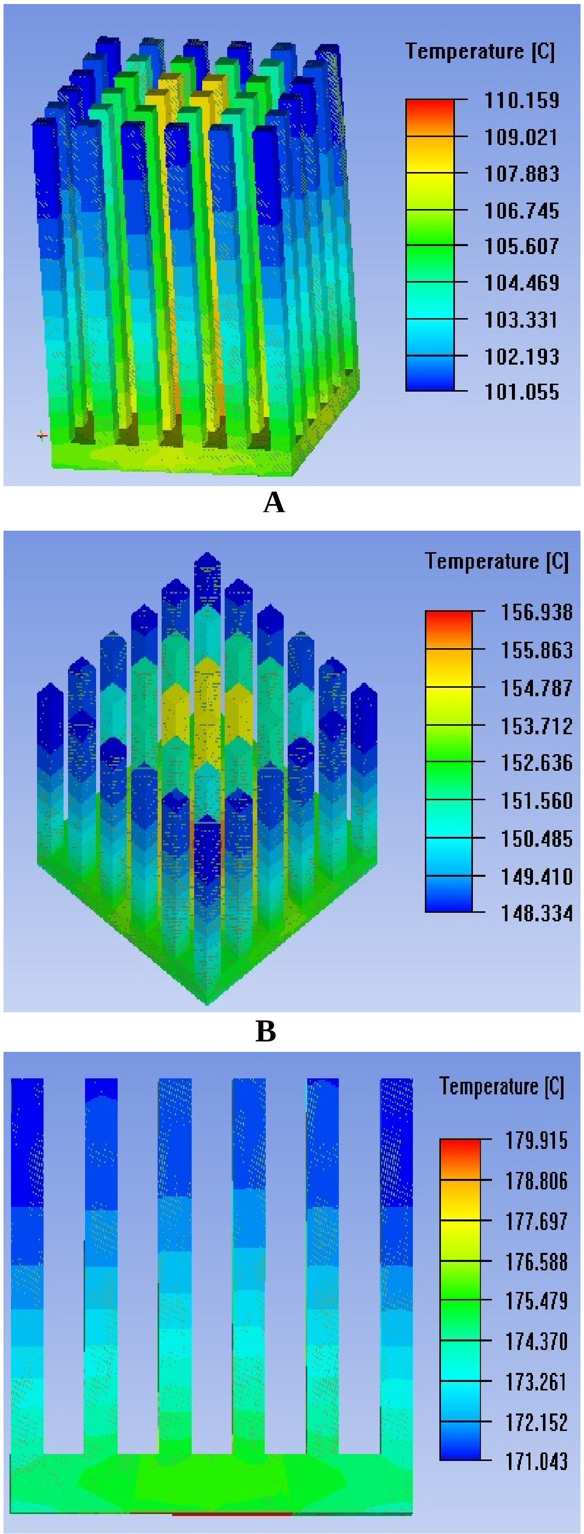


A

B

C

Fig (16) Temperature contour of Aluminum material cross pin fin heat sink (A) 0% carbon fiber (B) 40% carbon fiber, (C) 100% carbon fiber , Q=70 watt & U_{air}=0.5 m/s



A

B

C

Fig (17) Temperature contour of Copper material cross pin fin heat sink (A) 0% carbon fiber (B) 40% carbon fiber, (C) 100% carbon fiber , Q=70 watt & U_{air}=0.5 m/s

References

[1] Tian Tian, "Anisotropic Thermal Property Measurement Of Carbon-Fiber/Epoxy Composite Materials", *University Of Nebraska-Lincoln,* Theses-PhD, pp.19, December 2011.

[2] G. Kalaprasad, P.Pradeep, G. Mathew, C. Pavithran, And S. Thomas, "Thermal Conductivity And Thermal Diffusivity Analyses Of Low-Density Polyethylene Composites Reinforced With Sisal, Glass And Intimately Mixed Sisal/Glass Fibers", Csat, 60 (2000) 2967-2977.

[3] H. B. Shim, M. K. Seo, M and S. J. Park, "Thermal Conductivity and Mechanical Properties Of Various Cross-Section Types Carbon Fiber-Reinforced Composites", Journal Of Materials Science, 37 (2002) 1881-1885.

[4] Kuriger Rj, Alam Mk., "Thermal Conductivity of Thermoplastic Composites with Submicrometer Carbon fibers". Exp Heat Trans 2002; 15(1):19–30.

[5] Shinji Ogihara, Masato Okita, Junichi Shimizu[3], and Nobuo Takeda[4], "Experimental and Analytical Investigation Of Thermal Conductivity In Carbon Fiber Reinforced Plastics", Qing-Qing Ni (Shinshu Univ.), 30th November, 2005.

[6] Adnan A., Abdul Razak , Najat J. Salah and Waffa A. , " Electrical And Thermal Properties Of Epoxy Resin Filled With Carbon Black", Eng.& Tech. Journal,Vol.27,No.11,2009**.**

[7] Hyun S. Kim, Hyun S. Bae, Jaesang Yu & Seong Y. Kim, "Thermal Conductivity of Polymer Composites with the Geometrical Characteristics of Graphene Nano platelets", Scientific Reports 6, Article Number: 26825 (2016).

[8] Http://Www.Christinedemerchant.Com/Carbon_Characteristics_Heat_Conductivity.Html.

[9] Northern Illinois University - Department Of Mechanical Engineering Mee 390 Experimental Methods in Mechanical Engineering ©1990-1997 M. Kostic.

[10] Y. Plevachuk and V. Sklyarchuk, 2008, "Density, Viscosity, and Electrical Conductivity of Hypoeutectic-Cu Liquid Alloys", the Minerals, Metals & Materials Society.

[11] R. Mathiesen, L. A., P. B., and A. Somogyi, 2006, "Metal Mater", Trans. A, Vol. 37a.

[12] Incropera and De. Witt, "Fundamentals of Heat and Mass Transfer", Wiley 2000.

[13] Manuel V. and Amauri G., 2008, "Microstructural Development In Al-Ni Alloys Directionally Solidified Under Unsteady-State Condition", Metals & Materials Society.

[14] Michael J. and Richard H., "Advanced Boron Nitride Epoxy Formulations Excel In Thermal Management Applications", Nepcon West 1999 Conference, pp.359 - 366, Anaheim.

[15] T. Therisa, B. Srinivas , A. Ramakrishna, "Analysis Of Hyoid Structured And Perforated Pin Fin Heat Sink In Inline And Staggered Flow", Ijseat, Vol 2, Issue 4, April –2014.

[16] Yunus A. Cengelheat Transfer, A Practical Approach, Second Edition.

[17] Chris Long, Naser Sayms, Heat Transfer Exercise, Publishing Aps Ispn, 2010.

[18] Incropera and De. Witt, "Fundamentals of Heat and Mass Transfer", Wiley 2002.

[19] Jafar M. and Jussi V., " Copper Heat Sink Design, A Practical Application Of Mathematical Modelling", Outokumpu Research Center, Pori, Finland, Jussi.Vaarno@Outokumpu.Com.