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A STUDY OF EFFECT OF REINFORCING FIBERS DIRECTION FOR THE POLYMER COMPOSITES ON THE THERMAL CHARACTERIZATION USING COMPUTER MODELING

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ABSTRACT

The study was created using "ANSYS 5.4" the Physical CAD tool to find out the effect of fiber direction on thermal characterization for tow types of the polymer composites. One was the epoxy reinforced with Glass fibers composite (EGF), the other was the Polyester reinforced by the same type of fibers (PGF). The fibers angled with tow angles 00 and 450 with pivot of each type of the composites. The loads and boundary conditions (B.C) was applied as different temperatures. The study included temperature distribution, thermal flux and thermal gradient in which obtained directly from the package. The thermal conductivity withal was calculated from the results. The analysis showed that the temperature distribution is almost constant for all models, the thermal flux was 1743 (J/S.m2) for the EGF composites with 00 and 1494 (J/S.m2) for the 450, thermal gradient was 3134 (K0/m) for 0 0 and 4187 (K0/m) for 45 0. For PGF composites the values of thermal flux was 1799 (J/S.m2) for 00 and 1505 (J/S.m2) for 450, the thermal gradient was 3112 (K0/m) for the 00 and 4187 (K0/m) for 450. Thermal conductivity obtained from the previous results and the highest value was 0.578 (W/K0.m) for PGF 00, followed by 0.556 (W/K0.m) for EGF with the same angle of fibers. Other hand the other composites EGF and PGF with 45 0 had a lower values for thermal conductivity which were both about 0.36 (W/K0.m), for that reason we conclude that the last tow types (with 450 angle) were preferred to use in applications as water tanks or other thermal insulation systems.

Introduction

Generally the study of thermal characterization for the different materials[1] become an important problem especially in our present age, where the temperature began increases in a big amounts and affect the human comfort and economy [2][3].

This problem required a deep carefully study for a types of materials that have a better thermal insulation to reduce a factors like the Greenhouse Effect on the buildings [4], machines, or even a water containers [5]. This time most of the researchers using computer modeling within an assured packages, this packages considered to be guaranteed because it works on the numerical methods like integrated boundary condition (IBC)[6], Boundary element method (BEM)[7], and the most common method a Finite Element Method [8].

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This methods are insured and its results are proved to trusted for many important studies [7] [9][10].

In this study we chose a types of polymer composites which are glass fiber reinforced materials, this materials used in most of objects like water vessels and containers[11], which required materials and design give a best resistance to the sun rise and the weathering factors especially high continuous temperature loads. The current study confine on the effect of the fiber angle on the thermal characteristics for a type of polymer composites. In spite of this simple study is not a big achieving, but I hope that is a key for more better studies more depth, more types of materials, and more cases to study like radiation or other parameters affect on the climate. Thanks for Allah to help me in complete this modest research .

Theory

The heat flow H may be obtained as

$$H = KA\frac{dT}{dX} \qquad \text{------------------ 1}$$

Where: K is Thermal conductivity, A is the transversal surface area, dT is the temperature difference through which the heat is being transferred see fig(1) its unit Kelvin, dx is the thickness of the body of matter through which the heat is passing.

Thermal conductivity = Heat flow rate / (Area * Temperature gradient).

Which a may be written as : [12]

$$K = \frac{H}{A \times \dfrac{dT}{dX}} \qquad \text{------------------------ 2}$$

Now let's wade in FEA for the Heat Flow theory..

The first law of thermodynamics states that the thermal energy is conserved. Specializing this to a differential controllable volumes: [12]

$$\rho C\left(\frac{\partial T}{\partial t} + \{V\}^T\{L\}T\right) + \{L\}^T\{q\} = \ddot{q} \qquad \text{................ 3}$$

Where

C= Specific heat

T=temperature (=T(x,y,z))

T= time

$$\{L\} = \begin{Bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{Bmatrix} = \text{vector operator}$$

$$\{v\} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} = \text{velocity vector for mass transport of heat}$$

{q} = heat flux vector (output quantities TFx, TFy, TFz).

$\ddot{q}$ = heat generation rate per unit volume.

Next, Fourier's law is used to relate the heat flux vector to the thermal gradient:

$$\{q\} = -[D]\{L\}T \qquad \text{--------------- 4}$$

Where:

$$[D] = \begin{bmatrix} K_{xx} & 0 & 0 \\ 0 & K_{yy} & 0 \\ 0 & 0 & K_{zz} \end{bmatrix} = \textit{Conductivity matrix}$$

Kxx, Kyy, Kzz = Conductivity in the element x,y, and z directions, respectively.

{q}= -[D]{L}T ……..4

Combining equation 3,4 gives,

$$\rho C\left(\frac{\partial T}{\partial t} + \{V\}^T\{L\}T\right) = \{L\}^T([D]\{L\}T) + \ddot{q} \qquad \text{................ 5}$$

Expanding equation 5 to its more familiar form:

$$\rho C\left(\frac{\partial T}{\partial t}+v_x\frac{\partial T}{\partial x}+v_y\frac{\partial T}{\partial y}+v_z\frac{\partial T}{\partial z}\right)=$$

$$\bar{q}+\frac{\partial}{\partial x}\left(K_x\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial T}{\partial z}\right) \quad \text{...............} \; 6$$

It will be assumed that effects are in the global Cartesian system. Three types of boundary conditions are considered. It is presumed that these cover entire element.

1- Specified temperature acting over surface S1:

T=T* ……..7

Where T* is the specified temperature.

2- Specified heat flows acting over surface S2:

{q}T{η} = -q* ……..8

Where: {η}= unit outward normal vector

q* = specified heat flow

Specified convection surface acting over surface S3 (Newton's law of cooling)

$$\{q\}^T\{\eta\} = -h_f(T_B - T_S) \quad \text{................} \; 9$$

Where

Hf = film coefficient evaluated at (TB+TS)/2 unless otherwise specified for the element.

TB = bulk temperature of the adjacent fluid.TS = temperature at the surface of the model.

Note that positive specified heat flow is into the boundary (i.e. in the direction opposite of {η}), which accounts for the negative signs in equation 8,9.

Combining equation 4,8,9 gives:

$$\{\eta\}^T[D]\{L\}T = q^* \quad \text{............} \; 10$$

$$\{\eta\}^T[D]\{L\}T = h_f(T_B - T) \quad \text{............} \; 11$$

by multiplying equation 5 by a vertical change in temperature, integrating over the volume of the element, and combining with equations 10,11with some manipulation yields:

$$\int_{vol}\left(\rho C\,\delta T\left(\frac{\partial T}{\partial t}+\{v\}^T\{L\}T\right)+\{L\}^T(\delta T)([D]\{L\}T)\right)d(vol) = \quad \text{............}12$$

$$\int_{S_2}\delta T q^*\, d(S_2) + \int_{S_3}\delta T h_f(T_B - T)\, d(S_3) + \int_{vol}\delta T\, \dddot{q}\, d(vol)$$

Where: vol = volume of the element

δT= an allowable virtual temperature (δT(x,y,z,f))

Procedures

In this study we design two kinds of composites (depending on the matrix type). One was the Epoxy reinforced with glass fibers (EGF), the other was the Polyester reinforced with the same of glass fibers (PGF). The ANSYS package used to design and solve the models for each material depending on the fiber direction with the composite axis; the step of solving the models were:

a plate was design with (20x20 cm) dimensions to represent the area of the composite interfuse with tiny areas represent the fibers sites.

The fibers modeled as a unidirectional continues fibers angled at 00 and 450 respectively with the axis of each composite.

After completing the models geometry, the properties of each material has been entered to the ANSYS database, table 1 shows the properties for each material, and choosing the proper element, the used element was (Plane55)*1, and then completed the mesh. (fig2) illustrates the mesh for each model.

1- The boundary conditions (B.C) added for each model assumed to be a plate under different temperatures as shown in (fig3) below, the main load was (333^0 K) in the upper direction, the other directions have (B.C) as well as (308^0 K), The temperatures all must be in Kelvin(K°) in order to seek the units of thermal conductivity.

333K°=60C° is the temperature load, and 308K°=35C° are the boundary conditions (constraints or temperature at shade).

2- Finally, the analysis was run and the results obtained.

Results and Discussion

1. Temperature distribution

The distribution of temperature was constant and uniform almost for all the models (fig(4)), except a few differences in distribution for the composites with angled fibers as shown in figure (4-b,d) were considered a little shifting from the top lift side of the model for each material, this shifting can be assigned to the variation in fiber site in this region, where the middle diagonal area was clear (see fig 2-b) from the fibers with presence of them in other sides, and the upper lift area represent the start of length, likewise the upper side was the start of temperature load diffusion, all that caused a confused in that area in the angled fibers composites contra the composites with parallel fibers.

2. **Generally** figure (4) advert to extending of the temperature pattern from the upper side (load points) to the bottom as a half sin wave until arrive the middle of the model when deposit at a minimum value of temperature (308 K^0), also depositing on the other sides at the same value, the reason of this event was the effect of boundary conditions (B.C) on the model.

3. Thermal flux

The minimum and maximum values of thermal flux (T.F) for all models ordered in table-2, and figures (5-a-d) illustrates flux patterns on the models.

From the table above we see that the higher values of thermal flux existed in the models of parallel fibers (0^0); otherwise the polyester composites have the higher value from the Epoxy composite with the same type of reinforcing, the highest value of flux was (1799 $J/S.m^2$) for the polyester composite with parallel fibers, that means the heat transient in this type of composites is better than the Epoxy Composites in spite of the higher value of thermal conductivity for Epoxy resin used for these composites.

Another consideration from the analytical graphics (fig5), there is a clear different in thermal flux diffusion between the tow types of composites (0^0, 45^0) for each types of resin, figure (5-a,c) shows that the flux patterns pass from the upper side to the bottom through the fibers sites and direction of them, means the has the same behavior of temperature transient, but in the figure (5-b,d) the flux patterns take a diagonal track, that means the fibers work as a paths for flux passing, other word the fibers carrying the most thermal stresses.

Back to the table-2 and comparison the tow types (0^0,45^0) for the each material, we find that the minimum value of the flux for composites with 45^0 angled fibers is Zero, that means the angled fibers made a dead load regions in the composites which is more benefits in thermal isolation, this may be considered from figures (5- b, d), we can see the active flux patterns (the red color lines) vanishes after a little baths in the composite.

4. Thermal Gradient

Table-3 shows the values of thermal gradient (T.G) for all the models, and figures (6 a-d) illustrates the analytical results .

The table shows that the greatest value for thermal gradient for the types of 45^0 angled fibers composites, and the same types of materials have the same value of thermal gradient which mean there is no effect on the thermal gradient in case of angled fibers for the different materials, another consideration the minimum value for angled fiber composite is Zero (i.e the dead load regions or in other word this type is a good conservative for heating), the other evidence on the heating conservative the value of thermal gradient for the Polyester parallel fibers composite is a less than the same type of Epoxy composite reverse the case of thermal flux, which mean that the material which has a high thermal flux is a less isolator (heating conservator) than the material has a less value of thermal flux, in this case the Epoxy composite appear more heating conservator than Polyester composite for the same type of fiber distribution.

Back to the graphic results (fig-6) comparison (fig 6-a,b) and (fig 6-c,d), we find that there is another different in thermal gradient patterns with the difference of fibers distribution, this denotes that there is an effect for the angled fibers on the gradient path, likewise the graphics denoted that there is no active values of thermal gradient except on the top lift and right edges for all models, that is because of the low thermal conductivity for all the materials of the study.

5. Thermal conductivity

After obtained the values of thermal gradient and thermal flux for all the models, The values of thermal conductivity (K) was obtained by applying equation 2 on the maximum values for each material, the table-4 shows these values, figure (7) is a diagram illustrates the variation of values for all materials, and comparing them with the values of the original materials (resin and fibers).

Material	Fiber angle	K value (W/K^0.m)
Epoxy	-	0.2
Polyester	-	0.17
E-Glass fiber	0^o	1.3
EGF	0^0	0.556158
EGF	45^0	0.356819
PGF	0^0	0.578085
PGF	45^0	0.359446

From the results above, We found that that the material with better thermal conduction is the polyester composite with parallel fibers, followed by the value of epoxy composite with the same type of fibers, otherwise the composites with angled fibers have a less value, also the values were too closer for material to each other for the same type of fibers (the ratio between one to another about 96- 99%). The values of all composite materials are a greater than the values of original materials (except the fibers were a highest value of thermal conductivity).

Lastly, the epoxy composite with a fibers of (45^o) angle was found as a best insolated material from the other designed materials, but with a closer value with the same type of polyester composite , therefore, the best isolated and low cost material in this study is the polyester composite reinforced with the fibers aligned at (45^o).

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Table1- thermal properties for each matrix and fibers

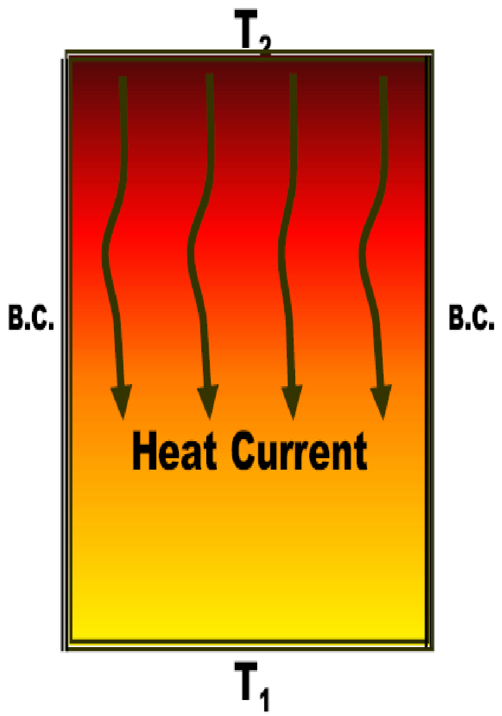
Material	Property	Amount in (MKS)
Polyester [13]	Thermal conductivity	0.17 W/m.K^0
	Thermal flux	63.75
	Thermal Gradient	375
Epoxy [14]	Thermal conductivity	0.2 W/m.K^0
	Thermal flux	75
	Thermal Gradient	375
E-Glass fibers [13]	Thermal conductivity	1.3 W/m.K^0
	Thermal flux	487.5
	Thermal Gradient	375

Table-2 minimum and maximum values of thermal flux

Material	Fiber angle	T.F value (J/s.m^2)	
		Min. value	Max. value
EGF	0^0	0.1	1743
	45^0	0	1494
PGF	0^0	0.11	1799
	45^0	0	1505

Table-3 minimum and maximum values for Thermal Gradient

Material	Fiber angle	T.G value (K^0/m)	
		min. value	max. value
EGF	0^0	0.56	3134
EGF	45^0	0	4187
PGF	0^0	0.59	3112
PGF	45^0	0	4187



fig(1) Heat translated in a plate from upper side with temperature T_2 to lower side with T_1(sample of thermal conduction)where $T_2 > T_1$

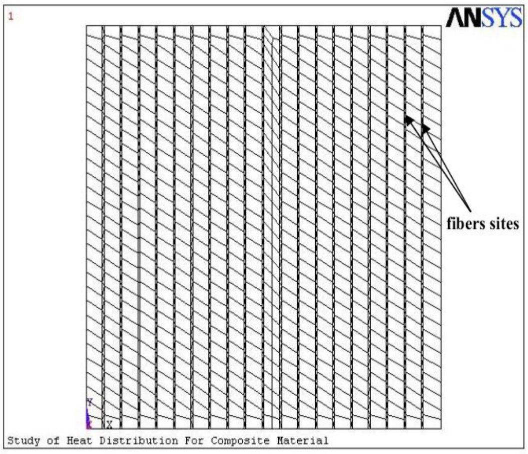
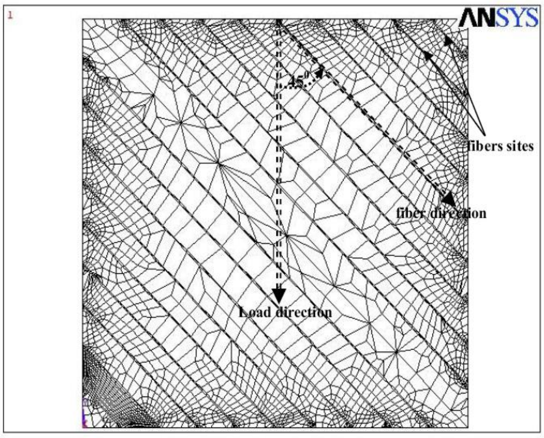
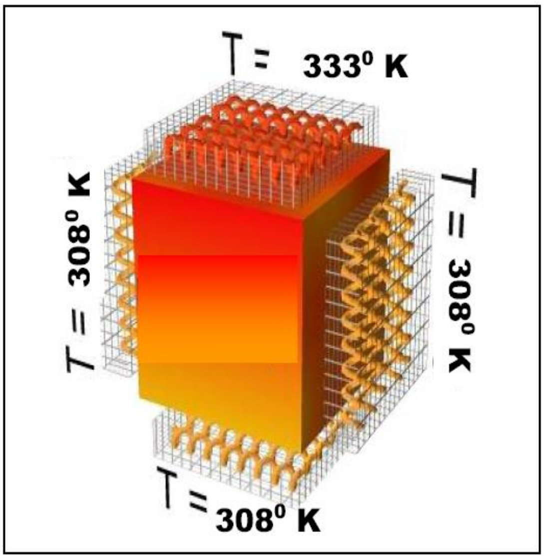


Fig (2-a) finite element mesh, fibers angled at 0^0 with the load direction

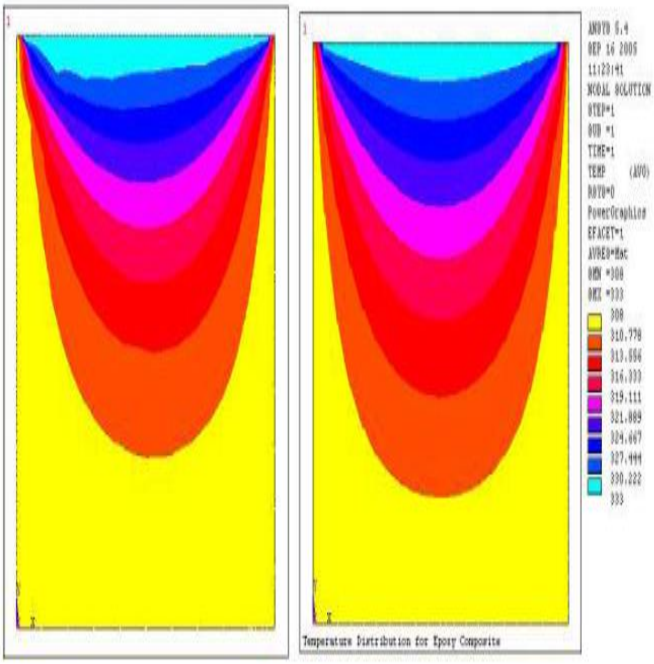


(Heat transfer direction through the model)

Fig (2-b) finite element mesh, fibers angled at 45° with the load direction

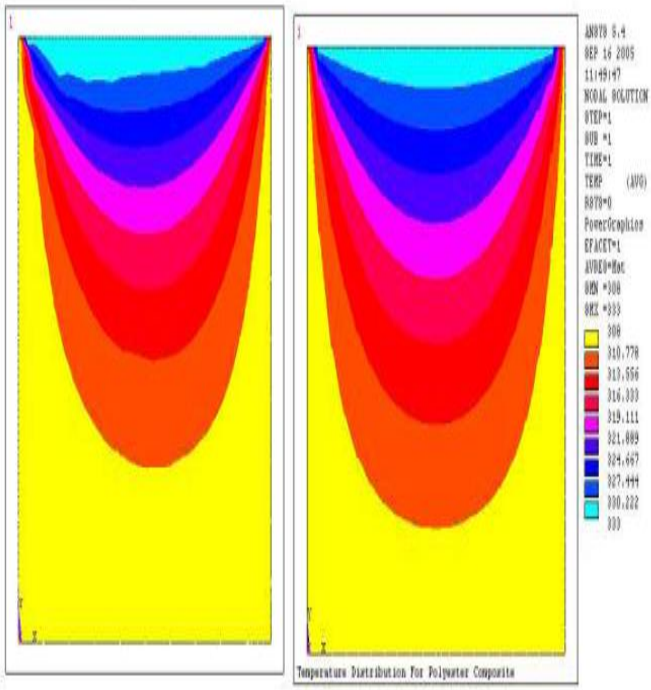


fig(3) Virtual simulation for the boundary conditions applied to the models



(b) (a)

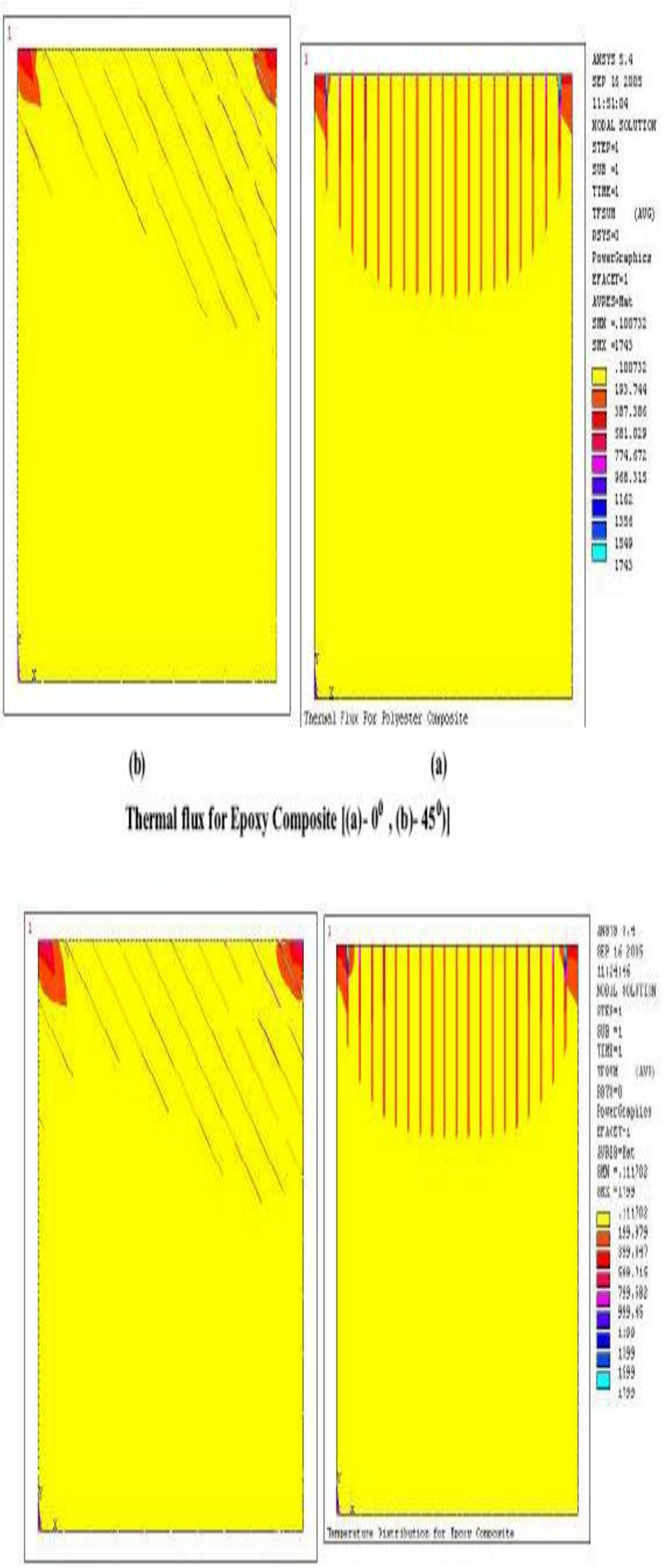
Temperature distribution for Epoxy Composite [(a)- 0^0 , (b)- 45^0)]



(d) (c)

Temperature distribution for Polyester Composite [(c)- 0^0 , (d)- 45^0)]

Fig (4, a-d) temperature distribution for all models



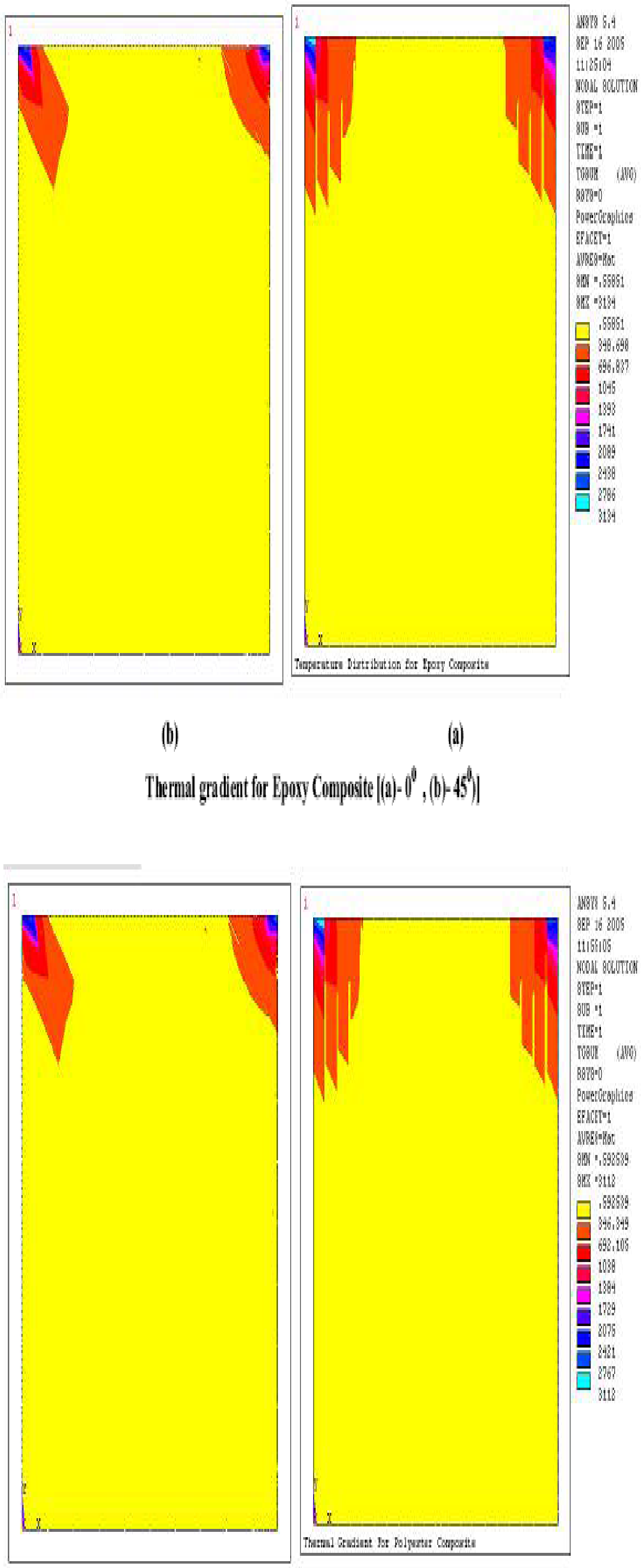
(b) (a)

Thermal flux for Epoxy Composite [(a)- 0^0 , (b)- 45^0)]

(d) (c)

Thermal flux for Polyester Composite [(c)- 0^0 , (d)- 45^0)]

Fig (5, a-d) Thermal flux for all models



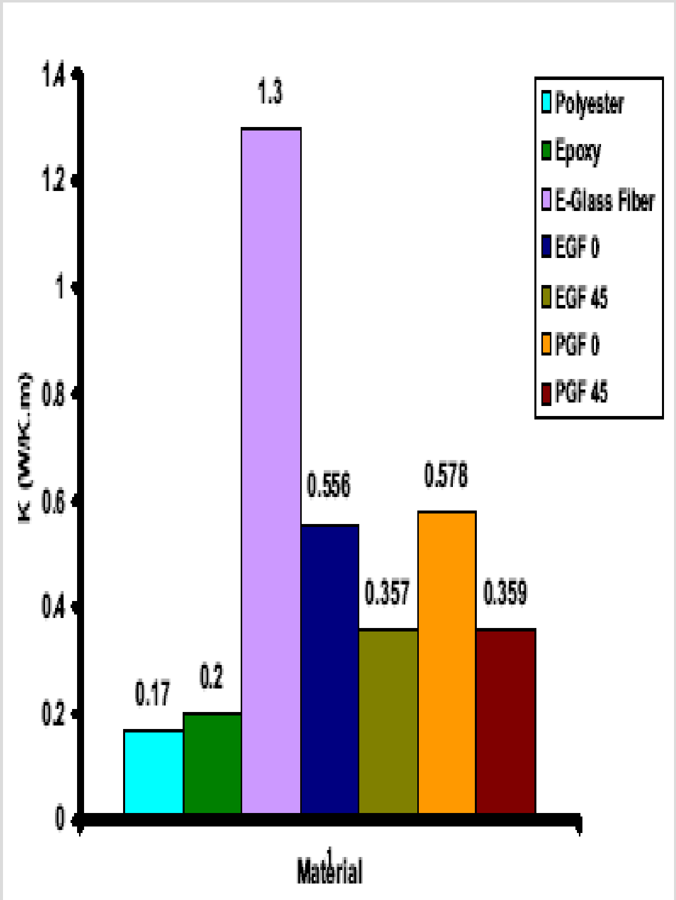
(b) (a)

Thermal gradient for Epoxy Composite [(a)- 0^0 , (b)- 45^0)]

(d) (c)

Thermal gradient for Polyester Composite [(c)- 0^0 , (d)- 45^0)]

Fig (6, a-d) Thermal gradient for all models



Fig(7) Thermal conductivity for all studied materials

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دراسة تأثير اتجاه ألياف التسليح على الخواص الحرارية للمتراكبات البوليمرية باستخدام التمثيل الحاسوبي

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ملخص

أجريت دراسة باستخدام برمجية الـ الحاسوبية لمعرفة تأثير اتجاه الألياف على الخصائص الحرارية لنوعين من المتراكبات البوليمرية (تصنف المتراكبات تبعاً للمادة الاساس وليس مادة التسليح) [my thesisP7L3] . إحداها متراكبة الايبوكسي المقواة بألياف الزجاج سميت اختصاراً (EGF)، النوع الآخر كانت متراكبة البولي استر المقواة بنفس النوع من الألياف وسميت (PGF). وضعت الألياف بزاويتين 00 و450 مع المحور الأساسي للمتراكبة. الأحمال والشروط الحدودية سلطت على هيئة درجات حرارية مختلفة. تضمنت الدراسة توزيع الدرجات الحرارية، التدفق والانحدار الحراري والتي حُصِّلت من البرمجية مباشرةً. بعد الحصول على النتائج السابقة تم حساب التوصيلية الحرارية للمواد. دلت النتائج على أن توزيع درجات الحرارة ثابت تقريباً لجميع النماذج، التدفق الحراري كان (J/S.m2) 1743 لمتراكبات EGF بزاوية 00 و (J/S.m2) 1494 للمتراكبة بزاوية 450، الانحدار الحراري كان 3134(K0/m) بزاوية 00 و 4187 (K0/m) للمتراكبة ذات الزاوية 450 . اما بالنسبة لعينات المتراكبة PGF فإن القيم كانت كالتالي. قيم التدفق الحراري كانت (J/S.m2) 1799 للزاوية 00 و (J/S.m2) 1505 للزاوية 450، أما الانحدار الحراري فقد كانت قيمته 3112 (K0/m) بزاوية 00 و 4187 (K0/m) للمتراكبة ذات الزاوية 45o. قيمة التوصيلية الحرارية حصلت من النتائج السابقة وكانت أعلى قيمة لها (W/K0.m) 0.578 للمتراكبة PGF بزاوية 00، تلتها القيمة (W/K0.m) 0.556 للمتراكبة EGF لنفس الزاوية. من ناحية أخرى كانت العينات ذات الزاوية 450 ذات اقل قيمة للإيصالية الحرارية والتي كانت لكلا النوعين تقريباً (W/K0.m) 0.36، من هذه الدراسة اتضح أن العينات الأخيرة (ذات الزاوية 450) من أفضل العينات المختبرة للاستخدام في تطبيقات العزل الحراري مثل خزانات الماء و أوعية الحفظ المعرضة لدرجات الحرارة العالية.