Study the Effect of Fibers Volume Fraction and their Orientations on the Properties of the Hybrid Composite Materials

Dr. Mohammed Sellab Hamza
Matterial Engineering Department, University of Technology/Baghdad
Email:dr.msh2013@yahoo.com

Received on: 9/5/2013 & Accepted on: 4/7/2013

ABSTRACT

This studying deals with the study of the effect of fiber volume fraction of the carbon, glass and Kevlar fibers and their orientation on the properties of Hybrid composite material. Different percentages of carbon, glass and Kevlar fibers were used to reinforce the matrix material (unsaturated Polyester). The fibers arranged in two methods according to the direction of the thermal flow. In the first method the fibers were parallel to the direction of the thermal flow, while the second method was perpendicular. The thermal conductivity measured by using Leeś disk. The experimental and theoretical results proved that the value of the of thermal conductivity increased with increasing the fiber volume fraction of the carbon ,Kevlar-49and glass and then reduced for Hybrid ($H_7$and H_8) for both arrangement parallel and perpendicular because do not hah carbon fiber. The thermal conductivity of parallel orientation had the highest value, while the carbon factor was the best. The experimental results of thermal conductivity for parallel arrangement indicated that the hybrid (H_6) had maximum value 3.40 W/m.k and for perpendicular was 0.245 W/m.k for hybrid (H٣).

دراسة تأثير الكسرالحجمي للألياف واتجاهاتها على خواص المواد المتراكبة الهجينة البوليمرية

الخلاصــة

فـــي هـــذا البحـث تـم دراسـة تأشيـر الكســرالحجمـــي لاليـــاف الكاربـــون والكلفـــر والزجـــاج وبنسـب مختلفـــة على خـواص المــواد المتراكبة الهجينة البوليمريـة. صنعت العينـات مــن مـــادة البولـــي استـرغيـر المشبـــع المقــواه باليـــاف الكاربـــون ,والكلفـــر,الزجـــاج. العينـــات صنعـت فـــي مجموعتين المجموعـــة الاولـــى كانـت فيهـا اليـــاف الكاربـــون مرتبـــة بشكـــل موازي للانسياب الحراري، اما المجموعة الثانية نضمت بترتيب الاليـاف بشكل عمودي على الانسياب الحراري. أستخدمت طريقة لي (Lees disk) لقيـــاس موصليـــة حراريـــة.

مـــن خـــلال فحـص العينات اثبتت ان الترتيب المـــوازي للاليـــاف يعطي موصلية حرارية اعلى وهي 3.40 W/m.k للهجيـن (H6). امـــا في الترتيـب العمودي فكانت اعلـــى موصليـــة حراريـــة وهـــي 0.239 W/m.k لنفـس الهجيـن.النتائج العملية اثبتت ان الياف الكاربون هي الافضل وتعطي اعلى موصلية حرارية.النتائج اكدت ان الموصلية الحرارية تزداد مع اضافة اليـاف الكـاربون والكفلـر والزجـاج لغايـة الهجين السـادس ثم تنخفض فـي الهجـين السـابع والثـامن لكونهمـا لايحتويان الياف الكاربون و لكلا المجموعتين المتوازية والعمودية.

https://doi.org/10.30684/etj.31.13A.3
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Notation

d_1, d_2 and d_3	Thickness of the brass disks (m)
d_s	Thickness of the composite specimen (m)
e	Convection heat transfer Coefficient (W/m^2. °C)
Kc	Thermal conductivity (W/m. °C)
K_{c1}	Thermal conductivity of the composite specimen in the parallel direction of the fibers (W/m. °C)
K_{c2}	Thermal conductivity of the composite specimen in the perpendicular direction of the fibers (W/m. °C)
K_f, K_m	Thermal conductivity of fibers and matrix (W/m. °C)
q	Heat flux.
r	Radius of specimen (m)
T_1, T_2,T_3	Temperature across the copper disks(1,2,3) (°C)
V_f	Volume fraction of fibers (%)
V_m	Volume fraction of matrix (%)
dT/dx	Temperature gradient (%)
v_c	Volume of composite material(%)
v_f	Volume of reinforced material(%)
p	Power pass though heating coil (watt)
i	Electric current pass though heating coil(Ampere)
v	Voltage across the terminal of heating coil(volt)
ρ_x , ρ_y , ρ_z	Density of composites , matrix and fibers

INTRODUCTION

Scientists in the field of engineering materials noticed that there are contrastive properties of engineering materials (metals, ceramics, and polymers) regarding strength (resistance), hardness and plasticity and their capabilities of bearing external forces, temperatures, etc…These properties could be appropriate for a certain application and not preferred for another. Metals are characterized of being heavy, quickly oxidized and corroded besides being capable of resisting great external forced. Ceramic materials, on the other have, can endure high temperatures and have a high compression force, yet they cannot stand impact loads as they are fragmental. Polymers have light weight, high plasticity and they do not stand external forces and do not oxidize [1and 2].

The need for a material that has some of the above mentioned properties led to the production of what is known as composites.

As a result of industrial development, composites (especially polymer composites) gained wide industrial fields due to their specifications and properties mostly required for use. Composites have become the foundation for changing and developing the engineering designs of many industrial goods and products, the most important of which is car industry, parts of aircraft and ships, building materials, chemical and sports uses etc….

Composites have the following properties:

1-Formation capability which makes it easy to make complicated forms.

2-Do not rust and corrode due to polarization property and root activity.

3-Good resistance to humidity and chemical materials.

4-Light weight and high strength which make it possible to obtain very high qualities.

5-Good insulators for temperature and electricity [3and4].

This work aimed to study the thermal conductivity of eight Hybrids which are manufactured from polyester reinforced with different volume fraction of carbon, Kevlar and glass fibers.

F.Rondeaux etal. (2001) developed a specific thermal conductivity measurement facility for solid materials at low temperature where the thermal conductivity measurements on pre-impregnated fibers glass epoxy composite are presented in the temperature of 4.2 K to 14 K for different thicknesses in order to extract the thermal boundary resistance [5].

Lamees A. Khalaf (2006) studied the mechanical and physical properties for unsaturated polyester reinforced by fiber glass and nylon fiber composites and found that the thermal conductivity decreases with the increase the volume fraction, it also decrease with increase of nylon fiber layers for the samples of laminar reinforced system[6] .

Saad M. Elie (2007)studied the mechanical properties and thermal conductivity for polymer composite material reinforced by aluminum and aluminum oxide particles and found that the thermal conductivity increased with the increase of the weight fraction of metallic and ceramic particles and reach a maximum value of (0.319 W/m.°C) for the composite material with (Al_2O_3) reinforced at a weight fraction of (20 %) and reached to (0.407 W/m.°C) for the composite material with (Al) reinforcement at the same weight fraction [7].

Qahtan Adnan (2008).Focused on the preparation of hybrid polymer matrix composite materials by (Hand Lay-Up) method, where the composite material was prepared from the unsaturated polyester resin (UP) as matrix reinforced by bidirectional woven glass fiber kind (E-glass) with afixed volume fraction of (10%) and graphite particles as first group of samples and the second group of samples reinforced with bidiraction woven Kevlar fiber kind (49) with afixed volume fraction of (10%) instead of glass fiber[8].

Hayder Raheem(2013) study the effect of Nanocarbon black on the properties unsaturated(UP) polyester and epoxy resins. He studies physical properties such as thermal conductivity and swelling test, also mechanical tests including tensile, compression, impact, bending, hardness and wear resistance. The experimental results indicated that the mechanical and physical properties are improvement [9].

THEORETICAL ANALYSIS

The physical and mechanical properties of composite material are calculated from the following relations.

The density of manufactured Hybrid was calculated from the following equation.

$$\rho_c = \rho_m . V_m + \rho_{f1} .V_{f1} + \rho_{f2} .V_{f2} \qquad \dots (1)$$

The volume fraction of both reinforced material and matrix material consider from important features which are effected on the properties of composites material, as a result of that the properties are effected such as density, modulus of elasticity, thermal conductivity and electrical conductivity … etc

The reinforced material is active within the composite material, so its volume fraction has more effective on the properties of material.

The volume fraction of matrix and reinforcement material is calculated from the following equations.

a- Volume fraction of matrix

$$V_m = \frac{v_m}{v_c}\% \quad \dots (2)$$

b- Volume fraction of fibers

$$V_f = \frac{v_f}{v_c}\% \quad \dots (3)$$

The thermal conductivity is defined by the following formula:

$$q = -k\ dT/dx \quad \dots (4)$$

The equation (4) used only for study state of thermal flow and when the thermal flux does not change with time. The minus sign means that the transfer of heat is starting from hot part to the cold part.

The theoretical thermal conductivity is calculating by the following equation:

$$K \cdot \left[\frac{T_2 - T_1}{d_s}\right] = e \cdot \left[T_1 + \frac{2}{r} \cdot \left(d_1 + \frac{1}{2} d_s\right) \cdot T_1 + \frac{1}{r} \cdot d_s \cdot T_2\right] \cdots (5)$$

The loss in heat (e) through the unit time (second) and through the area (m^2) is calculated from the following formula:

$$I \cdot V = \pi \cdot r^2 \cdot e \cdot (T_1 + T_3) + 2 \cdot \pi \cdot r \cdot e \cdot \left[d_1 \cdot T_1 + \frac{1}{2} \cdot d_s (T_1 + T_2) + d_2 \cdot T_2 + d_3 \cdot T_3\right] \cdots (6)$$

The theoretical thermal conductivity of composite materials is calculated from the following equations:-

1-when the direction of the thermal flow is parallel to the fibers, it is calculated from following equation:-

$$K_{c1} = K_m \cdot V_m + Kf1 \cdot V_{f1} + Kf2V2 \quad \cdots (7)$$

2-when the direction of the thermal flow is perpendicular; it is obtain from the following equation:

$$K_{c2} = \frac{Km \cdot Kf1.Kf2}{V_m \cdot K_{f1}.Kf2 + V_{f1} \cdot K_{f2}Km + .Vf2.Kf1.Km} \qquad ...(8)$$

EXPERIMENTAL WORK

In this work, the Lee's disk method is used for measuring the thermal conductivity. Hand Lay-up method was used for preparation the specimens, the geometry of the specimens are r =2Cm, ds =0. 6 Cm.

Table (1) illustrates the properties of unsaturated polyester and fibers of carbon, Kevlar and glass, while Table (2) represented the percentage of matrix (polyester) and reinforcement materials (fibers) as shown bellow.

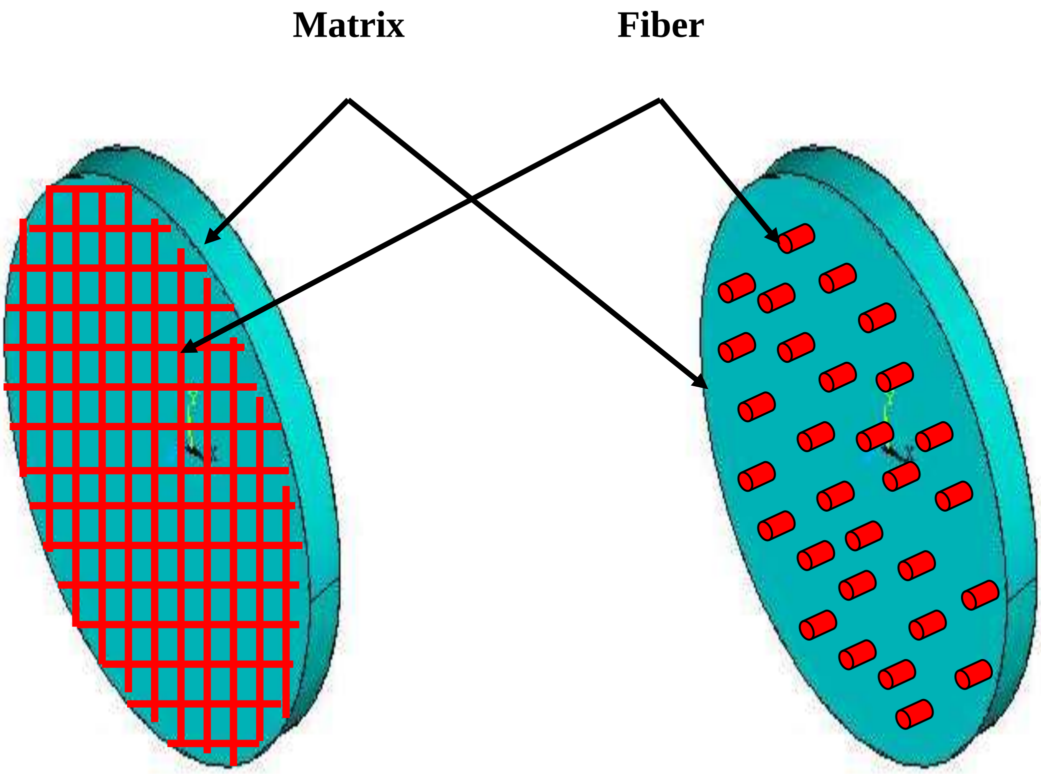
Table (1) the some Properties of Unsaturated Polyester and fibers of carbon, Kevlar, and glass [10]

Properties	Polyester	Carbon Fibers	Kevlar Fibers	Glass fibers
Density (g/cm^3)	1.04-1.46	1.78	1.44	2.58
Modulus of elasticity (GPa)	2.06-4.41	230	131	72.5
Poisson's Ratio	٠.33	0.32	0.47	0.22
Thermal conductivity ($W/m.^{o}k$)	0.17	11	1.68	1.3

Table (2) percentage of matrix and reinforcement materials.

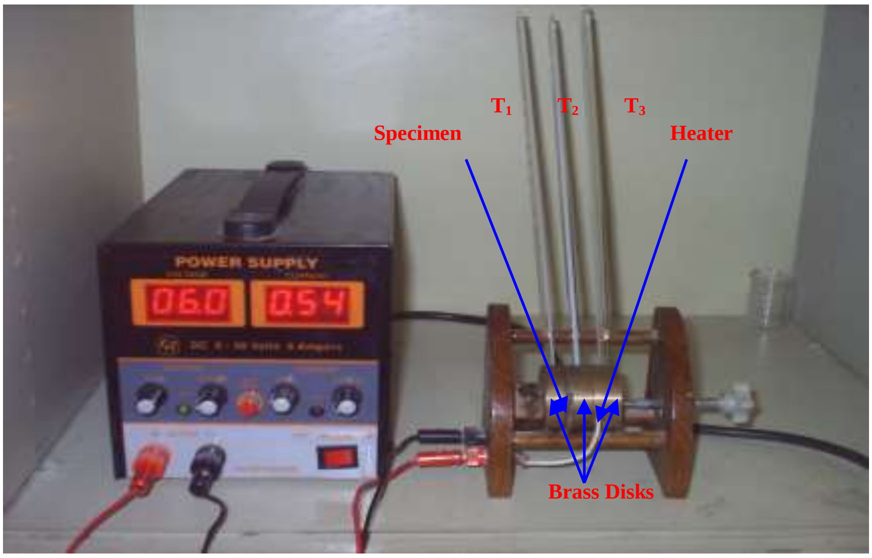
Designation of Hybrid	Matrix material	Reinforced Materials		
	Polyester %	Carbon Fibers %	Kevlar Fibers %	Glass Fiber %
H_1	70	20	5	5
H_2	70	22	4	4
H_3	70	24	3	3
H_4	70	26	2	2
H_5	70	28	1	1
H_6	70	30	0	0
H_7	70	0	30	0
H_8	70	0	0	30

The specimens reinforced with the fibers which arrangement in two ways the first is parallel to the direction of thermal flow and the second is perpendicular as shown in the Figure(1). The temperature across the copper disks (T1, T_2, T_3) were measured by means of Lee`s disk method as present in the Figure (2).



(a) Perpendicular to heat source **(b) Parallel to heat source**

Figure (1) Fiber Arrangement in the Specimen.



(a)

(b)

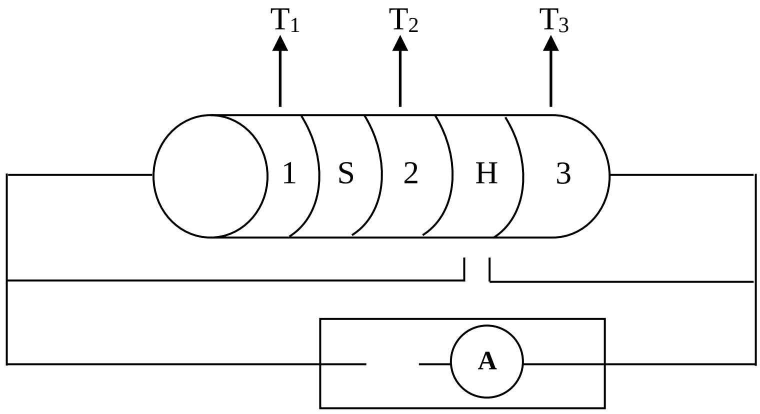


Figure (2) (a) shows the instrument of the thermal conductivity (b) the distribution of (T_1, T_2 ,T_3).

The applied voltage and current were (6v) (I=0.2A), to heat the copper disks (2,3) and the temperatures of all disks increases gradually where temperatures recorded every (5 minutes) until reach the equilibrium temperature of all disks.

The losses in heat (e) was calculated from equation (6).The experimental thermal conductivity (k) was calculated from equation (5) by using the experimental reading (T_1, T_2, T_3) and the dimension of specimen(r, ds). The theoretical values of the thermal conductivity for parallel arrangement were obtained from equations (7) and for perpendicular arrangement from equation (8).

RESULTS AND DISCUSSION

Table (3) shows the theoretical thermal conductivity of the composite specimen which had parallel and perpendicular arrangement. Table (4) illustrates the theoretical and experimental thermal conductivity for parallel arrangement and shows that the thermal conductivity increasing with adding fibers(carbon, Kevlar and glass) up to the Hybrid(H6) and then reduced to0.608 W/m.k and 0.496 W/m.k for Hybrids(H7 and H8) respectively. Because the Hybrid (H7) contain only Kevlar with polyester and the Hybrid (H8) contain only glass with polyester This indicated that carbon fiber is the best and give higher value of thermal conductivity. Theoretical and xperimental thermal conductivity for perpendicular arrangement is presented in the Table(5)which shows that the thermal conductivity increasing with adding fibers(carbon, Kevlar and glass) up to the Hybrid(H6) and then reduced to0.230 W/m.k and 0.229 W/m.k for Hybrids(H7 and H8) respectively because the same reasons. Table (6) illustrates the theoretical and Experimental results such as theoretical density and experimental density, volume and weight.

Figure (1) illustrates Fiber arrangement in the Specimen and the distribution of (T1, T_2, T3) while the Figure (2) shows the instrument of the thermal conductivity Figure (3) represent the percentage of materials for the fabricated hybrids (H1-H8), the percentage are as listed in Table (2).

Figure (4) shows the percentage of materials for hybrid (H1) which consist of Polyester 70%, Carbon fiber 20%, Kevlar fiber 5%, and glass fiber 5%. Figure (5) presents the percentage of materials for hybrid (H6) which composites of Polyster 70%, Carbon fiber 30%,Kevlar fiber 0%,and glass fiber 0% while Figure (6) shows

the percentage of materials for hybrid(H7) consist of Polyester 70%,Carbon fiber 0%,Kavlar fiber 30%, and glass fiber 0%.
Figure (7) illustrates the percentage of materials for hybrid (H8) which made of Polyester 70%, carbon fiber 0%, Kavlar fiber 0%, 4-Glass fiber 30%Figure (8)shows the experimental thermal conductivity for parallel arrangement which indicated that the maximum value is 3.40W/m.k for hybrid (H6) which consists of (70% polyester,30%carbon,0%kevlar,0%glass).,while the minimum value is 0.509W/m.k for (H8) which consists of(70% polyester, 0%carbon,0%kevlar,30%glass).

Figure (9) illustrates the experimental thermal conductivity for perpendicular arrangement which proved that the maximum value is 0.242W/m.k for hybrid (H6),while the minimum value is 0.509W/m.k for hybrid (H8) which fabricated from Polyester 70%,carbon fiber 0%,Kavlar fiber 0%, and glass fiber 30%.The both figures (8 and 9) emphases that the parallel arrangement is the best. Figure (10) shows the experimental thermal conductivity for parallel and perpendicular arrangement.

It was found that the maximum difference between the theoretical and the experimental results was (0.55%) for the parallel direction, while for perpendicular arrangement was (1.25%) this difference is accepted and it is due to the working conditions of the preparation and test of the specimens in the experimental work, while the equation of the theoretical thermal conductivity based on the ideal case.

Figure (11) shows the relationship between the experimental temperature of wall surface ($T_1$and T_2) of the tested specimens and the time for the Parallel arrangement to the Hybrid (H1) and the Figure (12) illustrates the same relation for Hybrid (H6). It is clear from these figures that the experimental temperatures of wall surface (T_2 and T_3) increase in nonlinear relationship with time until the equilibrium temperature (T_2=T_3) take placed.

Table (3) Theoretical Thermal Conductivity.

Designation of Hybrid	Theoretical Thermal Conductivity (W/ m-c^o)	
	Parallel	Perpendicular
H_1	2.468	0.237
H_2	2.658	0.238
H_3	2.848	0.239
H_4	3.038	0.240
H_5	3.229	0.241
H_6	3.419	0.242
H_7	0.623	0.231
H_8	0.509	0.230

Table (4) Theoretical and Experimental Thermal Conductivity for Parallel Arrangement.

Type of Hybrid	Theoretical Thermal Conductivity(w/m-c^o)	Experimental Thermal Conductivity(w/m-c^o)
H_1	2.468	2.443
H_2	2.658	2.613
H_3	2.848	2.808
H_4	3.038	3.003
H_5	3.229	3.189
H_6	3.419	3.400
H_7	0.623	0.608
H_8	0.509	0.496

Table (5) Theoretical and Experimental Thermal Conductivity for Perpendicular Arrangement.

Type of Hybrid	Theoretical Thermal Conductivity(w/m-c^o)	ExperimentalThermal Conductivity(w/m-c^o)
H1	0.237	0.233
H2	0.238	0.235
H3	0.239	0.245
H4	0.240	0.236
H5	0.241	0.237
H6	0.242	0.239
H_7	0.231	0.230
H_8	0.230	0.229

Table (6) Theoretical and Experimental results.

Type of Hybrid	Theoretical Density	Experimental Results		
		volume	weight	Density
H1	1.537	7.536	11.5828	1.536996
H2	1.5324	7.536	11.54813	1.532395
H3	1.5278	7.536	11.5133	1.527773
H4	1.5232	7.536	11.47881	1.523197
H5	1.5186	7.536	11.44414	1.518596
H6	1.514	7.536	11.4092	1.51396
H7	1.412	7.536	10.64081	1.411997
H8	1.754	7.536	13.21811	1.753995

CONCLUSIONS

The main conclusions of this research are:

1- The thermal conductivity of Hybrids is increasing with increasing of fiber volume fraction (V_f) and the best increasing for carbon fiber.
2- The thermal conductivity for parallel arrangement was higher than that for the perpendicular.
3- The Maximum difference between the experimental and theoretical values of the thermal conductivity was (0.55%) in parallel arrangement for Hybrid (H6) and was(1.25%) for perpendicular arrangement for the same Hybrid.
4- For parallel arrangement, the maximum experimental and theoretical values of the thermal conductivity were (3.٤٠ W/m, °C) and (3.419 W/m. °C) respectively, while for perpendicular were (0.2٤٥ W/m. °C) for Hybrid (H٣) and (0.242W/m. °C) for Hybrid (H_6).
5- The results indicated that the thermal conductivity depends on the method of the arrangement of reinforcement materials and the type of fibers.
6- The using of reinforcement material (carbon, Kevlar and glass fibers) increased the thermal conductivity of polyester from (0.17 W/m. °C) to maximum value (3.40 W/m. °C) in the H_6 for parallel arrangement, and to (0.2٤٥ W/m. °C) in the H_3 for perpendicular arrangement.

REFERENCES

[1]. Zhan – Sheng Guo, Shanyi Du and Boming Zhang, “Temperature Distribution of the Thick Thermoset Composite”, Journal of Modeling and Simulation in materials Science and engineering, Volume 12, issue 3, (China) may, (2004).

[2].BSR Murthy, Dr. A. Rama Krishna and B.V Rama Krishna,” Thermal Analysis of Epoxy Based Fiber-Reinforced”, IE(I) Journal – MC, Vol.84, April, (2004)

[3].Oronzio Manca, Biagio Morrone, Giuseppe Romano, “Analysis of Thermal Response of Composite Materials “, Dipartimento Ingegneria Aerospaziale

[4. Raimund Rolfes,” 2D Finite Element Formulation for 3D Temperature Analysis of Numerical Simulation of Heat Transfer”, Journal of numerical simulation of heat transfer, Germany, May, (2001).

[5]. Rondeaux, F. Ph. Bready and J.M. Rey, “Thermal Conductivity Measurements of Epoxy Systems at Low Temperature”, Cryogenic Engineering Conference (CEC), (USA), July (2001).

[6]. Lamees A. Khalaf, "Studying the mechanical and physical properties for unsaturated polyester reinforced by fiber glass and nylon fiber composites", M.Sc. Thesis, University of Technology, Materials engineering Department (2006).

[7]. Saad M. Elie, "studied the mechanical properties and thermal conductivity for polymer composite material reinforced by aluminum and aluminum oxide particles", M.Sc. thesis, University of Technology, Materials engineering Department (2007) .

[8].Qahtan Adnan Hamad Al-Jbouri (2008) study mechanical and physical properties for polymer matrix composite material reinforced by fibers and particles.

[9]. Hayder Raheem”sudy the effect of nano powder on the properties of the composite material “(2013). M.Sc Thesis, Materials engineering college, university of Al- Mustansiriya.

[10]. Callister,W. D. "Fundamentals of Materials Science and Engineering", 4th Department of Metallurgical Engineering the University of Utah, John Wiley & Sons, Inc. **(2000).**

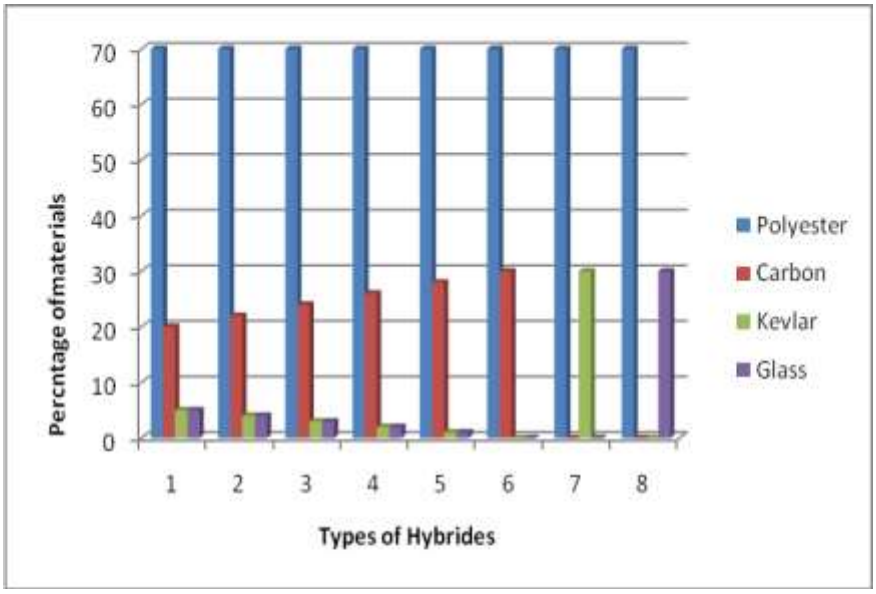


Figure (3) percentage of materials for hybrids (H1-H8).

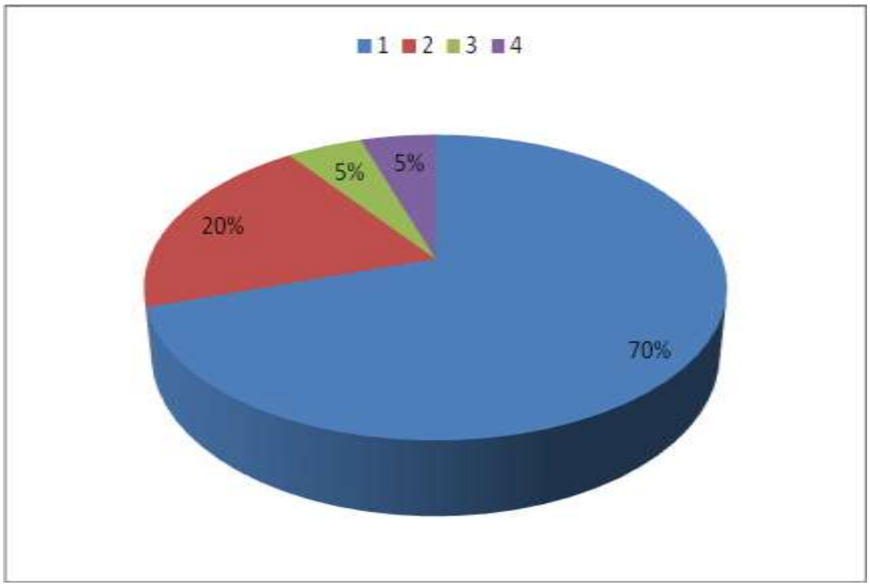


Figure (4) percentage of materials for hybrid (H1).
1-Polyester 70%, 2-Carbon fiber 30%, 3-Kavlar fiber 5%, 4-Glass fiber 5%.

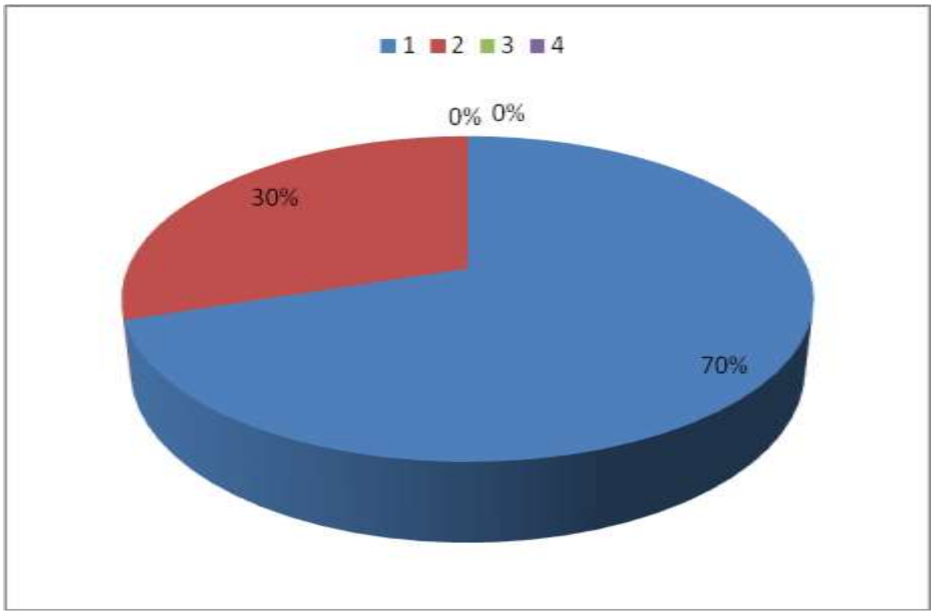


Figure (5) percentage of materials for hybrid (H6):
1-Polyster 70%, 2-Carbon fiber 30%, 3-Kavlar fiber 0%, 4-Glass fiber0%.

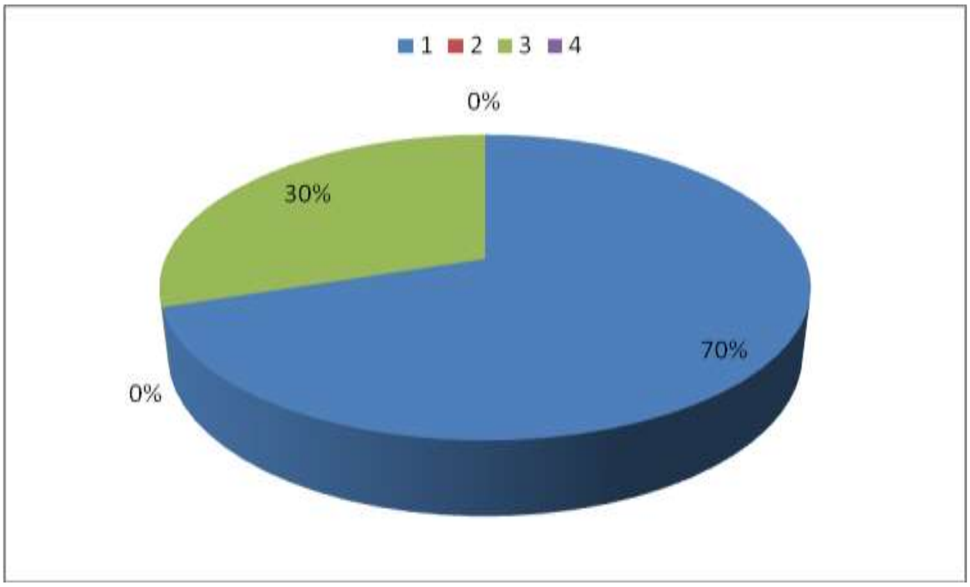


Figure (6) percentage of materials for hybrid (H7):
1-Polyster 70%, 2-Carbon fiber 0%, 3-Kavlar fiber 30%, 4-Glass fiber 0%.

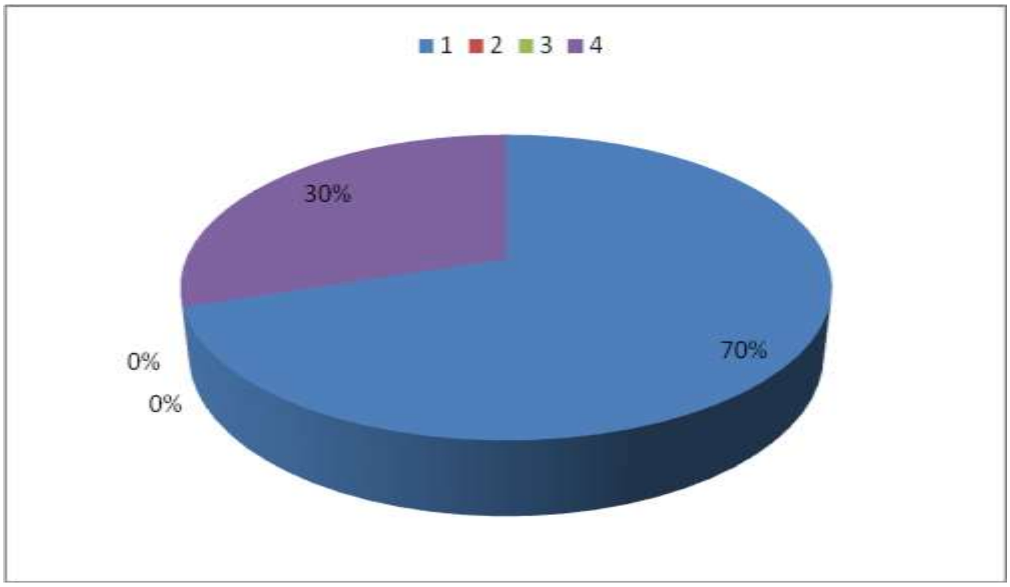


Figure (7) percentage of materials for hybrid (H8).
1-Polyster 70%, 2-Carbon fiber 0%, 3-Kavlar fiber 0%, 4-Glass fiber 30%.

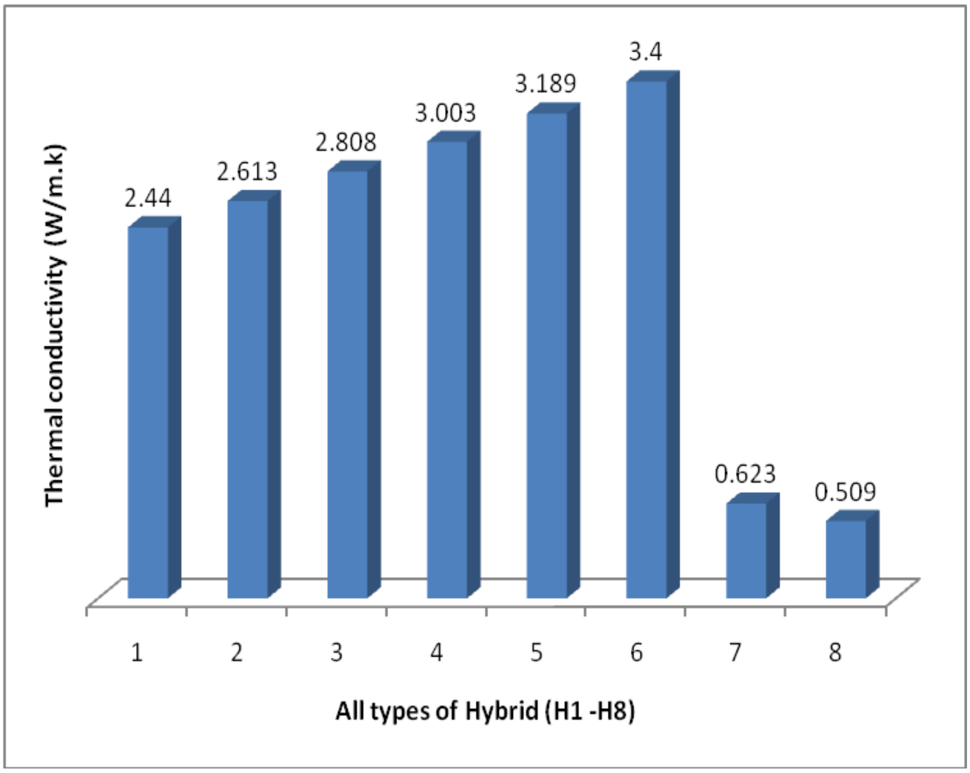


Figure (8) Experimental thermal conductivity for parallel arrangement

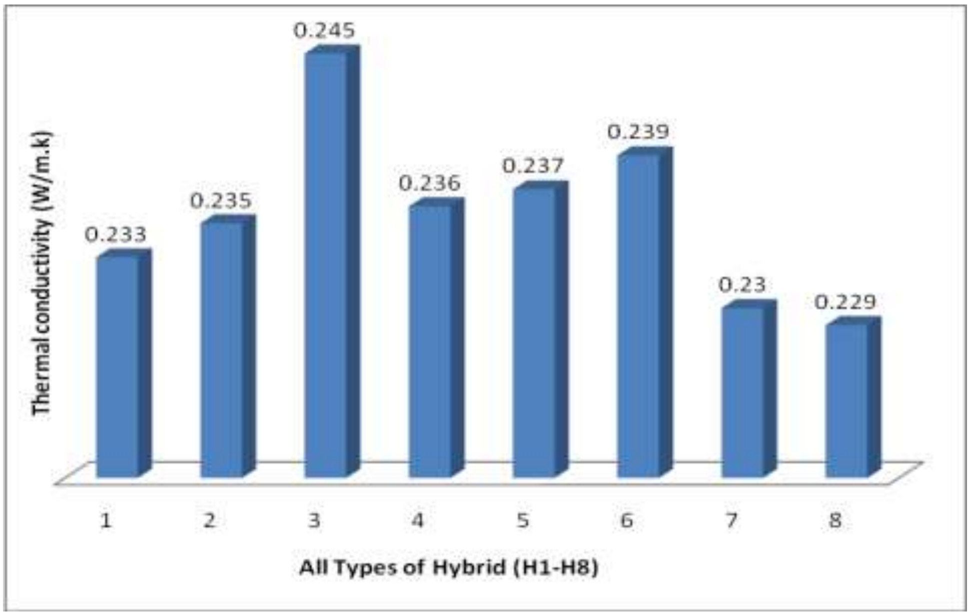


Figure (9) Experimental thermal conductivity for perpendicular arrangement

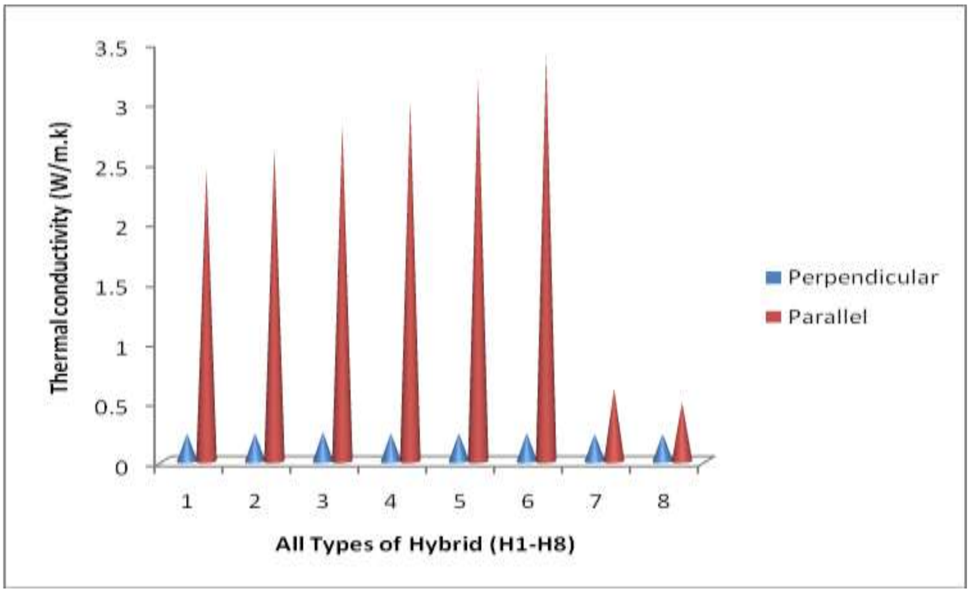


Figure (10) Experimental Thermal Conductivity for Parallel and Perpendicular Arrangement.

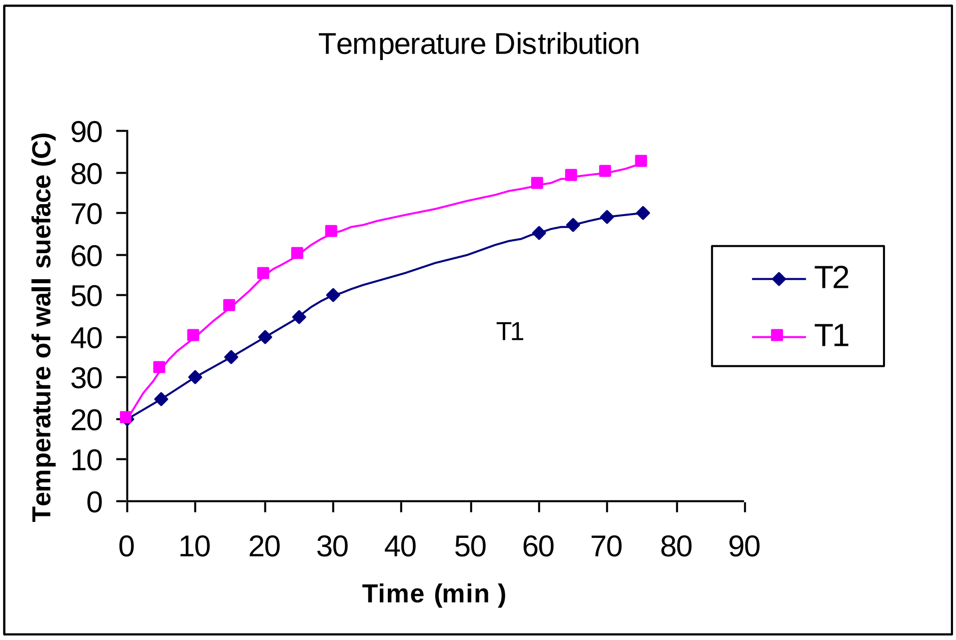


Figure (11) Relationship between the experimental temperature of wall surface ($T_1$and T_2) of the tested specimens and the time for Hybrid (H1)for parallel arrangement

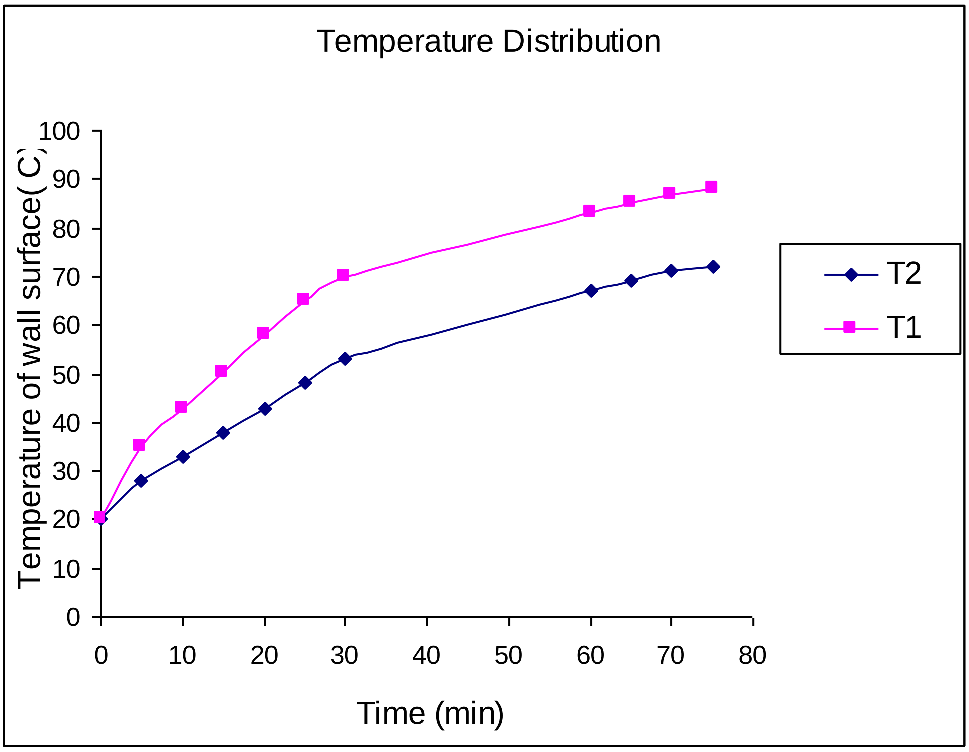


Figure (12) Relationship between the experimental temperature of wall surface ($T_1$and T_2) of the tested specimens and the time for Hybrid (H6) for parallel arrangement