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Micro and Nano of ZnO Particles Effect on Some Mechanical and Thermal Properties of Epoxy Resin Composites

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ABSTRACT

Effect of Micro and Nano particle of Zinc Oxide on the mechanical and thermal conductivity properties of an epoxy micro and nanocomposite were studied. Micro and nanocomposites were prepared using Open template method and by different weight ratios of micro and nano of ZnO particles having an average size of (45 µm) and (50 nm), respectively. The mechanical properties of micro and nano-composites were studied using Mechanical measuring devices including tensile strength devices, Shock resistance and Shore hardness Effects of ZnO micro and nanoparticles on the curing behavior of these micro and nanocomposites were investigated utilizing lee disc method. It was found that, ZnO micro and nanoparticles can effectively influence on the mechanical and thermal properties of epoxy coating. In addition, as the results showed an improvement in the mechanical properties of the epoxy compound supported with nanoparticles better than the compound supported with micro-particles, The values of hardness (81,82,82.4, and 83 N/mm^2) for the microcomposites and (81.2,82.8,83, and 84 N/mm^2) for the nanocomposites compared its value (79) for pure epoxy and the impact values (17.5,18.75,21.25, and 26.25kJ/m^2) for the microcomposites and (18,21.25,23.75, and 27.5kJ/m^2) for the nanocomposites compared its value (16.25) for pure epoxy and for the ratios (0.1,0.3,0.5, and 0.7 wt%) respectively , while the results showed a decrease in the thermal conductivity of the epoxy compound supported by micro and nanoparticles with an increase in the weight ratios. Micro and Nano particle of ZnO

Introduction

In the past decades, nanosatellites which called CubeSats also, have changed the scene for the space missions, especially for exploring the orbit of Earth. Cubesats have also been widely used as technology Appearances, scientific tools, and in educational purposes [1, 2, and 3]. Due to the importance of nanoparticles different types have been produced and depending on the painting property that needs enhancement. As one of the most important paints, due to the excellent properties that it can produce, nanocomposites reinforced with zinc oxide is also one of such materials that has been of interest in recent years. The optical, chemical and biological properties for the paint consider among the most important features. These nanoparticles can also improve the photolysis resistance of the paint by absorbing and blocking ultraviolet rays. Epoxy paint is used in the manufacture of composites as a basis, this is why it is characterized by low resistance to ultraviolet rays. As well as it is very important to improve this property. In addition, ZnO nanoparticles are a non-toxic semiconductor material that produces environmentally friendly paints [5, 6]. Although it has been found that the resistance of anti-corrosion paints including these nanoparticles can be improved in better way [7], So Epoxy resins have been widely used in industrial applications. It has strong adhesion and affinity with heterogeneous materials [9, 10]. Nanoparticles have been used in recent years as advanced fillers materials to improve the mechanical and chemical properties of Epoxy resin [11,12]. These nanoparticles can fill cavities in Epoxy and close cracks. [13]. Usually, Epoxy materials are used as paints. However, it is rarely used as pure material.

Different ratios are added frequently which lead to improve mechanical, physical, thermal and electrical properties, etc. [14, 15]. It is clear that the final properties of resulting heterogeneous material depend on number of factors, such as the concentration and the type of doping block, the distribution and size of the filler particles in the polymer matrix and their size, and the nature of the interaction of the matrix with the filler material. [16, 17, 18, 19]. Previous studies showed that this technique enables an individual to effectively identify mechanical properties (elasticity modulus, creep and hardness) [20,21].

The aim of this study is to study the effect of micro and nano zinc oxide particles on the mechanical properties and thermal behavior of micro and nanoparticles of epoxy particles and determine which is better

Experimental

Samples preparations

Composites of epoxy-ZnO micro and nano particles were prepared using manual molding method at room temperture . To this end, fillers of micro and nano particles of ZnO, at different weight ratios (0.1, 0.3, 0.5, and 0.7wt%), were added to epoxy resin matrix of Quikmast 105 Base of low viscosity **(3-5 poise @ 25 °C,1-2 poise @ 35 °C)** and density (**1.1± 0.05 g/cm³**) manufactured by (Forsoc Jordan) and its ratio (3: 1) is added to it as a hardener of the same type of resin, which reacts with epoxy at room temperature, the micro and nano particles of ZnO were purchased from Company with average size 45µ, Assay 99.9 % made in Barcelona Espana and Company with average size 50 nm,made in USA (MW=81.83,Assay 99.5 %) respectively were added to the epoxy as supported materials . Solution mixture (resin and ZnO particles) were sonicad for 25 min using (ultrasound bath) to increase the dispersion of ZnO particles in the epoxy solution. In order to increase of homogenously of solution mixture, the mixture was mixed using magnetic stirrer device for 30 minutes at room temperature, then the hardener was added to epoxy with a ratio of (1: 3).), and placed on a device (magnetic stirrer) for fewl minutes to complete the mixing. then the mixture is poured onto glass substrates with dimensions (15 * 15 * 0.4 cm^3). The poured samples were left for two weeks to complete the hardening process, Then the samples were cut with different dimensions according to type of test, For the purpose of performing tests of tensile strength, Impact, hardness and thermal tests, instruments were used (Laryee Technology-WDW-50 model,Shore D from Check-line dd-100 type Izod Impact Test Factory by a company Time Groub and Lee's Disc Factory by a company Griffen and George respectively), Where the equations were used to find the weight ratios [22]:

$$V_P = \frac{\rho_c}{\rho_P} W_P \times 100\ \% \qquad (1)$$

$$V_m = \frac{\rho_c}{\rho_m} W_m \times 100\ \% \qquad (2)$$

As :Density of each substrate, stiffener, and composite material $_c\rho\ _p,\rho\rho_m$,

W_m, W_p :The weight fraction of the base material and the reinforcing material

Result and discussion

Tensile Strength can be calculated from the following equations:-

$$T.S_{max} = \frac{F}{A} \qquad (3)$$

As: $T.S_{max}$: Maximum tensile strength in units (N / m^2), F: Force at failure in units (N).

A: The cross-sectional area of the sample at failure in units (mm2) [23].

stress can be calculated from the following equation: [24]:-

$$\sigma = \frac{F}{A} \qquad (4)$$

As: F: The force exerted in units (N)., A: Sample cross-sectional area in units (m^2).

Strain can be calculated from the following equation [20]:-

$$\varepsilon = \frac{\Delta L}{L_o} = \frac{L - L_o}{L_o} \qquad (5)$$

L: The final length of the sample in units(m). , L_o: The original length of the sample in units(m)., L The amount of change in length, in units(m).

Elasticity or Young's Modulus, and it can be expressed by the following equation [26]:-

$Y_m = \frac{\sigma}{\varepsilon}$ (6), Y_m: Unig Modulus in units (N / m^2)

The shock durability is calculated from the following equation [26]:-

$I.S = \frac{U}{\varepsilon}$ (7), I.S = Shock Durability, measured in units (KJ / m^2). , U = Fracture Energy in units (KJ)., A = Area of section in units (m^2).

The thermal conductivity of a poor thermal conductivity material is measured using the Lee's Disc Method calculated from the following equations [27]:-

$k\{(T_B-T_A) / ds\} = e[\ T_A + r/2\ (d_A + ds/4)\ T_A + ds\ T_B/2r\ ]$ (8), (e: the amount of thermal energy passing through the unit area of disc material per second (W / m^2. K), calculated from the following equation:-

$IV = \pi r^2 e\ (T_A+T_B) + 2\pi\ r\ e\ [d_A\ T_A + ds\ /2\ (T_A+T_B) + d_B\ T_B + d_C\ T_C]$ (9), T_A, T_B , T_C : disk temperature (A, B, C) respectively, measured in units (C °)., d: thickness of the disc in units (m).

r: the radius of the disk in units (m)., I: the current passing through the heater coil in units (Amper). , V: the potential difference at both ends of the heater coil in units of (Volt).

Figures1 (a) and (b) show the (stress and strain) curves of epoxy compounds supported by micro and nano ZnO particles and with different weight ratios respectively. Figure (3) shows the relationship between the highest stress value and the various ratios. Their values are shown in Table 1(a) and (b). Through the figures 1 (a) and (b), we note that the values of tensile strength and maximum tensile strength increase with the increase in the weight ratios of fine and nano zinc oxide particles compared to the epoxy resin before adding the particles. From the (stress - strain) curve of the epoxy resin before addition in figures1 (a) and (b), we find that the relationship is a linear relationship because it consists of an elastic deformation zone, and with the increase in the applied pressure beyond the point of submission (which is the boundary between the elastic deformation zone and the ductile deformation zone) and with constant pressure the cracks expand which lead to Fractures. The reason behind this is due to the intertwining of the polymeric chains that make up the sample. This is mean that the material will need more pressure in order to occur the fracture. As the nano and micro particles distribute the pressure over all parts of the sample. Here, the influence of nano and micro particles in obstruction the growth of these small cracks [28]. It is noted from Figure 2 (a) that the values of the highest stress value are greater in the case of support with nanoparticles because in the case of adding nanoparticles and when applying tensile stress there is a difference in the diffusion mechanism. This can be attributed to the difference in the partial support phase and nanoparticles, as well as the fact that the strength of the interconnection in the interface space of the nanoparticles (zinc oxide). The epoxy resin will affects the deformation of the bond with the increase in the fraction. Thus, the volumetric effect of nanoparticles in addition to the effect of agglomeration has led to decrease in the transfer of the load between the nanoparticles and the resin [29]. From the relationship between stress and strain, we were able to obtain the values of the elastic modulus of the basic material and its complexes. We also notice from Figure 2 (b), which shows the relationship between the elastic modulus (E) with the percentage of weights. For the material supported by the micro and nano scale, Then the increasing of the elasticity modulus in a non-linear relationship with the increase of the weight ratios of the added semiconductor material, except for the ratio (0.7%) in the nanoparticles, as it was observed at this ratio similar to the saturation limit in the values of the elastic modulus, this means a decrease of the particles movement then leads to reduction in strain, that is, to an increase in the brittleness of the polymeric material. There are many factors that may influence the elasticity values modulus of the composite material which are the accumulation of fillers, adhesion quality, elastic properties and the substrate viscosity. [30] In comparison with the Young's modulus values for both types of nanoparticle and microparticle supported samples, we note that the Young's modulus values are greater than Samples supported with micro-particles of zinc oxide. The reason for this is due to the nature of the chemical-physical interaction and the bonding between the nanoparticles and the base material which plays a fundamental role in determining the mechanical behavior as zinc oxide nanoparticles have higher connections than zinc oxide nanoparticles [31].

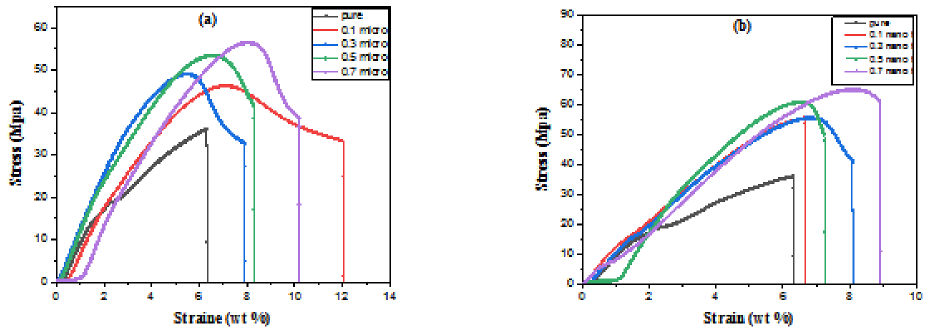

Fig. 1: shows the relationship between stress and strain curves for the epoxy compositions supported by (a) ZnO microparticles (b) ZnO nanoparticles.

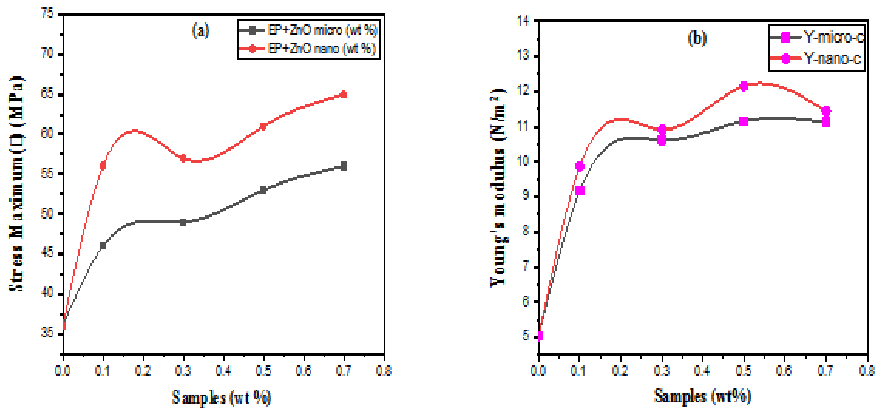

Fig. 2: shows the relationship between (a) the highest tensile stress value (b) Young's modulus and the different ratio of micro and nanoparticles of ZnO.

Table 1: shows the values of tensile strength, strain maximum , and young coefficient of epoxy compound supported by (a): micro and (b) nano zinc oxide minerals by different weight ratios

Table (a)

Samples EP+ZnO micro (wt %)	Tensile Strength σUTS (MPa)	Ultimate Strain ε_f(%)	Young's Modulus Y.M(GPa)
pure	36	6.3	5.041
0.1	46	6.5	8.3
0.3	49	6	10.7
0.5	53	7	11.0
0.7	56	8	11.12

Table (b)

Samples EP+ZnO nano (wt %)	Tensile Strength σUTS (MPa)	Ultimate Strain ε_f(%)	Young's Modulus Y.M(GPa)
pure	36	6.3	5.041
0.1	56	6.7	9.87
0.3	57	6.8	10.92
0.5	61	7	12.164
0.7	66	8	11.45

Hardness Test

Figure 3 shows that the hardness of the epoxy material increases in a non-linear relationship by adding both types of particles. Both micro and Nano particles increase resistance of material to deformation depending on how the particles are distributed within the base material in addition to their participation in bearing stresses on the composite material. Besides the base material because the particles themselves have high strength and hardness [32], it is also noted that the increase in the added percentage of particles led to an increase in the hardness than it used to be when adding the particles. This is why, the increase in the area occupied by the particle phase in the polymeric phase of the composite material, as well as the nature of the used nanoparticles which work as obstacles to deformation of the base material because of the high hardness for these micro and Nano particles. On the other hand, the distribution of this additive in the soft ground (epoxy material) to increases the hardness of the produced composite. In view of the small size of the nanoparticles, during the manufacturing process, they are easily penetrated into the base material and in the interstitial voids and pores that form during the preparation of the compound. This, in turn, increases the contact area between the components of the prepared composite material, and then increases the interconnection between them in an integrated manner. This gives the so-called closed space (convergingly spaced) more positive values when testing the hardness, considering it a measure of the plastic deformation that can occur in the material under external influence. Therefore, the addition of nanoparticles increases the hardness of the material due to its increased resistance to plastic deformation [33, 34, and 32]. Table (2) shows the hardness values for epoxy compounds that reinforced with particles and Nano zinc oxide.

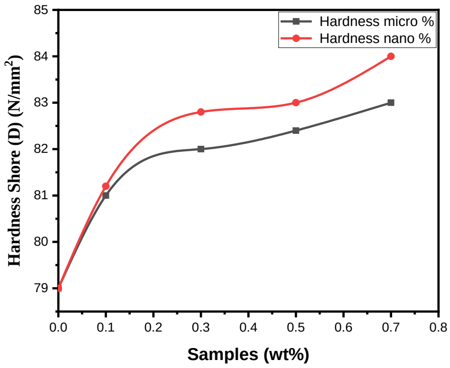

Fig. 3 shows relationshipe between the hardness values and the different ratio of micro and nanoparticles of ZnO.

Table 2: shows the hardness values of epoxy material supported by micro and nano zinc oxide with different weight ratios.

Samples EP + Zno micro	Hardness Shore (D) (N/mm^2)	Samples EP + Zno nano	Hardness Shore (D) (N/mm^2)
EP	79	EP	79
0.1	81	0.1	81.2
0.3	82	0.3	82.8
0.5	82.4	0.5	83
0.7	83	0.7	84

Impact Test: Figure 4 shows the effect of changing the gravity part of the absorbed energy that required to break the epoxy supported with micro and Nano zinc oxide particles with different weight ratios. So we notice that the absorbed energy required for fracture increases when reinforced with micro and nanoparticles of ZnO. As well as, at adding and increasing the weight of both types of micro and nanoparticles, this will increase the shock resistance. So, Both of micro and nanoparticles impede the fracture state because they bear the biggest part of the load imposed on the sample as a result of the support material acting as a barrier in front of the crack that develops through the composite material, as it will impede the growth of the crack and this will lead to changing the crack and its direction by turning it into a group of secondary cracks. This change in the shape and direction leads to increase the fracture surface area. Table (4) shows the shock resistance values of epoxy compounds supported by micro and nanoparticles of zinc oxide, where we note that the values of shock strength in the case of support with zinc oxide nanoparticles are greater compared to the support case with micro zinc oxide and the reason for this is due to the compatibility nature of this type of nanoparticles With epoxy [35].

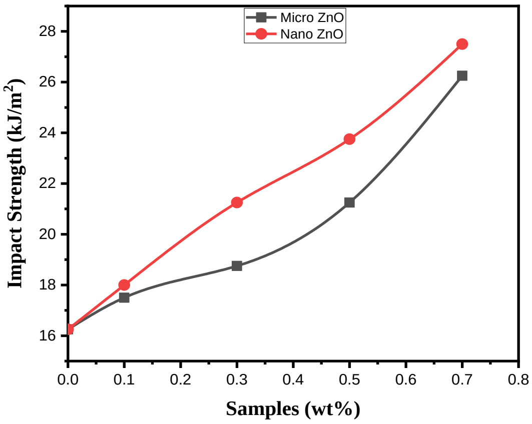

Fig. 4: shows relationshipe between the shock teste values and the different ratio of micro and nanoparticles of ZnO.

Table 3: shows the shock values of the epoxy compound supported with micro and nanoscale zinc oxide fines with different weight ratios.

Samples (wt %)	Width d(mm)	Thickness S (mm)	Area A=S×d 10^{-6} (m^2)	Impact Energy (Joule)	Impact Strength GC(kJ/m^2) EP+ZnO micro	Impact Energy (Joule	Impact Strength GC(kJ/m^2) EP+ZnO nano
pure	**0.01**	**0.004**	**4**	0.65	16.25	0.65	16.25
0.1	**0.01**	**0.004**	**4**	0.70	17.5	0.72	18
0.3	**0.01**	**0.004**	**4**	0.75	18.75	0.85	21.25
0.5	**0.01**	**0.004**	**4**	0.85	21.25	0.95	23.75
0.7	**0.01**	**0.004**	**4**	1.05	26.25	1.10	27.5

Thermal Conductivity Test

The thermal conductivity was calculated by applying equation (6, 7) and calculating the thermal conductivity modulus of epoxy compounds that supported by micro and nanoparticles of zinc oxide with different weight ratios. We notice through Figures 5 (a) and (b) that the value of the thermal conductivity modulus of pure epoxy is (0.40256W / mK) and its value increases to (0.81285W / mK) when supported by micro zinc oxide particles to (0.63898W / mK). When it supported by zinc oxide nanoparticles, the reason behind this is the arrangement of zinc oxide particles and the increase in air gaps between the particles beam and the resin, as well as the directivity of the particles row [34]. As for adding and increasing the fraction weight of micro and nano zinc oxide particles, we note that the value of the thermal conductivity modulus begins to decrease with the increase in the added percentage. But the value of thermal conductivity modulus remains higher than its value in the case of pure epoxy. This is why that the structural vibrations of the resin begin in decrease in the addition of nanoparticles to the resin. This will serves to impede the structural vibrations responsible for the thermal transfer in the resin and thus the value of the thermal conductivity modulus decreases [36].Table (5) shows the values of the thermal conductivity coefficient of the epoxy compounds supported by the micro and nanoscale zinc oxide.

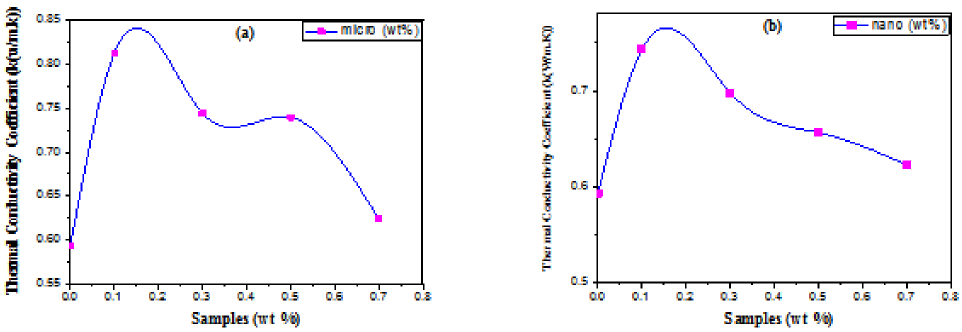

Fig. 5: shows relationshipe between the thermal conductivity coefficient and the different ratio of (a) micro and (b) nanoparticles of ZnO.

Table 4: Shows the thermal conductivity coefficient values of epoxy compounds supported by micro and nano zinc oxide particles with different weight ratios.

Samples(wt%)	Thermal Conductivity Coefficient k(W/m.K) EP+ZnO micro	Thermal Conductivity Coefficient k(W/m.K) EP+ZnO nano
EP	0.593368	0.593368
0.1	0.812245	0.74317
0.3	0.744046	0.698268
0.5	0.739596	0.656655
0.7	0.623973	0.623387

Conclusions

The influence of addition of zinc nanoparticles on mechanical and thermal properties. The study showed that micro and Nano ZnO particles were well dispersed and distributed in the epoxy matrix, with few agglomerations that could be observed. The addition of micro and Nano particles of zinc oxide enhanced epoxy matrix and its mechanical strength, as well as increased hardness and shock resistance values with compared to unmodified epoxy with addition of weight ratios of micro and Nano particles of ZnO. On the other hand, the addition of up to 1 % of micro and nanoparticles of ZnO led to decrease in the thermal resistance. Also a slight decrease in thermal stability could be attributed to the catalytic effect of ZnO through the formation of a complex between Zn and oxygen from the oxirane ring and the carboxyl group in Nano epoxy, The study also showed that the results of fortification with nanoparticles are better than microparticles for most of the tests and for all weight ratios.

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تأثير جسيمات اوكسيد الخارصين المايكروية والنانوية على بعض الخصائص الميكانيكية والحرارية لمتراكبات راتنجات الايبوكسي

اسماعيل صالح محمد ، جاسم محمد منصور ، هند وليد عبدالله

قسم الفيزياء ، كلية العلوم ، جامعة ديالى ، ديالى ، العراق

الملخص

تمت دراسة تأثير اضافة الجزيئات المايكروية والنانوية لاوكسيد الخارصين على الخصائص الميكانيكية والتوصيل الحراري لمتراكبات راتنجات الايبوكسي المايكروي والنانوي. تم تحضير المتراكبات المايكروية والنانوية باستخدام طريقة القولبة اليدوية وبنسب وزن مختلفة من جزيئات أكسيد الخارصين المايكروية والنانوية وبمتوسط حجم (45 µm) و (50 nm) على التوالي، تم اجراء فحوصات الشد والصلادة والصدمة والفحوصات الحرارية بأستخدام أجهزة مقاومة الشد وصلادة شور (D) و مقاومة الصدمة وجهاز قرص لي على التوالي للمتراكبات المايكروية والنانوية، واظهرت النتائج ن جزيئات اوكسيد الخارصين المايكروية والنانوية يمكن أن تؤثر بشكل فعال على الخواص الميكانيكية والحرارية لطلاء الإيبوكسي، بالإضافة إلى ذلك، حيث أظهرت النتائج تحسنًا في الخواص الميكانيكية لمتراكب الايبوكسي المدعم بالجسيمات النانوية بشكل أفضل من المتراكب المدعم بالجسيمات المايكروية، اذ بلغت قيم الصلابة ($81,82,82.4, \text{ and } 83\ N/mm^2$) للمتراكبات المايكروية و ($81.2,82.8,83, \text{ and } 84\ N/mm^2$) للمتراكبات النانوية مقارنة مع قيمه ($79N/mm^2$) للإيبوكسي النقي وكانت قيم الصدمة ($17.5,18.75,21.25, \text{ and } 26.25\ kJ/m^2$) للمتراكبات المايكروية و ($18,21.25,23.75, \text{ and } 27.5\ kJ/m^2$) للمتراكبات النانوية مقارنة مع قيمة ($16.25\ kJ/m^2$) للايبوكسي النقي وللنسب ($0.1,0.3,0.5, \text{ and } 0.7\ wt\%$) على التوالي، بينما أظهرت النتائج انخفاضًا في الموصلية الحرارية. من متراكب الايبوكسي المدعم بالجسيمات الدقيقة والنانوية مع زيادة نسب الوزن للجسيمات المايكروية والنانوية من اوكسيد الخارصين، بينما أظهرت النتائج انخفاضًا في التوصيل الحراري لمتراكبات الايبوكسي المدعمة بالجسيمات المايكروية والنانويةمع زيادة النسب الوزنية من المادة المضافة .