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Study the effect of sodium hydroxide solution on the thermal conductivity of nanocomposites

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Abstract

In this research, hand lay- up technique is used to prepare samples from epoxy resin reinforced with multi- walled carbon nanotubes in different weight fractions (0, 2, 3, 4, 5) wt%. The immersion effect by sodium hydroxide solution (NaOH) at normality (0.3N) for a period of (15 days) on the thermal conductivity of nanocomposites was studied, and compared to natural condition (before immersion). The thermal conductivity of epoxy nanocomposites specimens were carried out using Lee's disk method. The experimental results showed that thermal conductivity increased with increase weight fraction before and after immersion for all specimens, while the immersion effect leads to decrease thermal conductive values compared to thermal conductivity values in natural condition.

Key words

Epoxy resin, carbon nanotube, nanocomposite, thermal conductivity.

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دراسة تأثير محلول هيدروكسيد الصوديوم على التوصيلية الحرارية لمادة متراكبة نانوية

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الخلاصة

في هذا البحث أُستخدمت تقنية القولبة اليدوية (Hand Lay – up) في تحضير عينات من راتنج الإيبوكسي المدعم بأنابيب الكربون النانوية متعددة الجدران (MWCNTs) بنسب وزنية مختلفة (0، 2، 3، 4، 5) wt%. تم دراسة تأثير الغمر في محلول هيدروكسيد الصوديوم (NaOH) ذو عيارية (0.3N) وبدرجة حرارة المختبر لمدة (15 يوم) على التوصيلية الحرارية للمتراكبات النانوية، ومقارنتها بالحالة الطبيعية (قبل الغمر). لقياس التوصيلية الحرارية لنماذج متراكبات الإيبوكسي استخدمت طريقة قرص لي (Lee's disk). أظهرت نتائج الدراسة ان التوصيلية الحرارية تزداد بزيادة النسب الوزنية للمادة المضافة ولجميع العينات قبل وبعد الغمر في المحلول القاعدي. في حين لوحظ إن الغمر بالمحلول القاعدي يؤدي الى نقصان قيم التوصيلية الحرارية لكافة العينات مقارنة بقيم التوصيلية الحرارية في الحالة الطبيعية.

Introduction

Polymer nano composites are a new kind of polymeric materials. They have polymer (epoxy, polyester, …etc) as a matrix material, and nano additives are utilized as reinforcement material. The nano additives can be 1-D (fibers and nanotubes), 2-D (layered materials like clay) or 3-D (spherical particles). Polymer nano composites have been gaining a great deal interest both in industrial and academia because of their outstanding electrical, thermal and mechanical properties with small concentration of nano additives [1]. On the other hand, polymers have excellent properties such as high durability, lightweight, easy processing, ductility, corrosion resistance and low cost. Compared to metals and ceramics, polymers have relatively poor thermal, electrical and mechanical properties. Polymers are less dense than metal and ceramic materials, they have a low coordination number and light weight atoms of hydrogen and carbon as a backbone, which makes them find applications as construction materials and structural components in light weight applications like defense, automobile, electronics and aerospace [2].

Polymer matrix composites reinforced with carbon nanotubes have become popular in the structural applications due to very high aspect ratio, unique atomic structure and singular properties like flexibility and strength of carbon nanotube [3]. Carbon nanotubes are the most famous nanomaterials since its discovery by Japanese scientist S. Iijima in 1991. Carbon nanotubes allotropes of carbon with a cylindrical nano structure [4, 5].

Carbon nanotubes are classified as single-walled carbon nanotubes (SWCNTs), double-walled carbon nanotubes (DWCNTs) and multi-walled carbon nanotubes (MWCNTs). They with unique characteristics because of small size, high surface areas, stronger than steel (50 – 100 time) with only one – sixth its weigh and others. The MWCNTs consist of multiple layers of graphite rolled in on themselves to form a tube shape. The outer walls on multi-walled nanotubes can protect the inner carbon nanotubes from chemical interactions with outside materials. MWCNTs have a larger diameter (from 10 up to 100 nm) compared with SWCNTs, which is in the range of 0.4 - 5.6 nm. MWCNTs are also more rigid, because their section is much larger compared to that of SWCNTs [6, 7].

The main applications of carbon nanotubes are electronics, polymer composites, sensors (gas sensor), and hydrogen storage [8].

Thermally conductive polymer matrix composites present new possibilities for replacing metallic parts in a number of applications including electric motors and generators, heat exchangers, power electronics, etc. Current attentions to improve the thermal conductivity of polymer materials are focused on the selective addition of nano fillers with high thermal conductivity. Because of high thermal conductivity of CNTs, this property makes them the best promising candidate material for thermally conductive nano composites [9].

B. Bahjat Kadhim, et al. [10] studied effect the reinforcement with carbon nanotubes on thermal conductivity for nanocomposites. Nanocomposites were prepared by adding multi wall carbon nanotubes in different volume fractions (0, 0.1, 0.2, 0.3, 0.4) vol% into epoxy resin. Hand lay-up method was used to prepare nanocomposites. The experimental results shown that thermal conductivity increase with increasing of volume fraction of (MWNCTs).

N. Kadhim Taieh, et al. [11] studied effect the chemical and swelling resistance of epoxy with functionalized multi-wall carbon nanotubes (FMWCNTs) composites. Nanocomposites were prepared by adding multi wall carbon nanotubes in weight fraction (0, 0.1, 0.2, 0.25, 0.5) wt% to epoxy resin. The results shown that chemical and swelling resistance of epoxy increase with increasing wt% of FMWCNTs.

T. M. Al-Saadi, et al. [12] studied the effect of multi wall carbon nanotubes on some physical properties of epoxy matrix. Fore samples were prepared by adding multi wall carbon nanotubes in weight fraction (0, 2, 4, 6) wt% to epoxy resin. The hand lay-up technique has been used to prepare sheets of composites. The results showed the increase of hardness, thermal conductivity, electrical conductivity and break down strength with the increase of MWCNT concentration, but the behavior of dielectric loss factor and dielectric constant is opposite that.

R. M. Hussein [13] studied the effect of walled nano-carbon on the physical, thermal and mechanical properties of epoxy. Nanocomposites were prepared by adding MWCNTs in different weight fraction (0, 0.1, 0.5, 1) wt% to epoxy resin. The results showed that thermal conductivity, glass transition temperature and hardness are slightly increases as the filler percentage increased.

The aim of this study is to prepare nano composite specimens in different weight percentage (0, 2, 3, 4, 5) wt% by adding MWCNTs into epoxy resin, and study the effect of MWCNTs content on thermal conductivity of nano composites by Lee's disk. Also study the effect of immersion in sodium hydroxide solution on thermal conductivity of nano composites and compared to natural condition.

Theoretical part

The property that describes the ability of the material for transferring heat is called thermal conductivity. It is best defined in terms of the expression [14]:

$$Q = -K\frac{dT}{dX} \qquad (1)$$

where Q: is the heat flux.
K: thermal conductivity coefficient.
$\frac{dT}{dX}$: is the temperature gradient through the conductive medium.

The negative signal in the above equation indicates that the direction of the thermal flow from the high-temperature region to the low-temperature region. Methods of measuring thermal conductivity are divided into two categories, dynamic and static. Eq. (1) is suitable only for steady- state heat flow.

There are several methods to measure the thermal conductivity of solid materials depending on the nature of these materials [15]. If the material is dielectric or has poor thermal conductivity as in polymers, the thermal conductivity (k) is measured using the Lee's disk method.

Lee's disk method belongs to the static category. In this method the substance (S) is placed between two copper disks (A, B). The electric heater (H) is placed between two copper disks (B, C). The temperatures of the copper disks (A, B, C) are measured by using thermometers. The heating coil in Lee's disc apparatus provides with D.C voltage V = 6 Volts and current I = 0.25Amp which are held constant for all samples [8]. The thermal conductivity (k) can be experimentally calculated using the following relationship [16]:

$$K\left(\frac{T_B-T_A}{d_S}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \frac{1}{4}d_S\right)T_A + \frac{1}{2r}d_S T_B\right] \qquad (2)$$

where e: is the amount of thermal energy passing through the disk per second (W/m^2.^{o}C). It is calculated from the following equation:

$$H = IV = \pi r^2 e(T_A + T_B) + 2\pi re\left[d_A T_A + d_S\frac{1}{2}(T_A + T_B) + d_B T_B d_C T_C\right] \qquad (3)$$

where r: is radius of the disk.
d_S: is sample thickness.
d_A, d_B, d_C: are thickness of disks A, B and C, respectively.

Experimental work

1. Used materials

1.1 Polymer: The polymer used in this study is epoxy resin (Euxit 50 KI) supplied by Egyptian Swiss chemical industries company. It convert to a solid state by adding its hard (Euxit 50 KII) supplied by the same company at ratio of (1:3). The properties of epoxy resin used in this work are shown in Table 1 according to Product Company.

Table 1: The properties of epoxy resin

Color	Density (g/cm^3)	Compression strength (MPa)	Tensile strength (MPa)	Percent elongation at break (EL%)	Modulus of elasticity (MPa)
Pale yellow	1.05	70	27	<6	2800

1.2 Filler: The material used as filler throughout this study is multi- walled carbon nanotubes manufactured by the Cheep Tube Inc. (USA). The properties of MWCNTs are explained in the Table 2.

Table 2: The properties of MWCNTs.

NO.	Properties	Quantity
1	**Purity**	90%
2	**Inner dimension**	5-10 nm
3	**Outer dimension**	10-30 nm
4	**Length**	10-30 μm
5	**Specific surface area**	>200 m^2/g
6	**Bulk density**	0.06 gm/cm^3
7	**True density**	~2 gm/cm^3

1.3 Immersion solution: immersion solution used in this study is sodium hydroxide solution (NaOH) has normality (0.3N) supplied by the material laboratory in university of Anbar. All specimens were immersed in a base solution for (15 days).

2. Preparation of nanocomposites

A hand lay-up was utilized to prepare epoxy/MWCNTs composite sheets. The epoxy resin was mixing with its hardener in the ratio of (3:1) continually and slowly by using a glass rod in order that avoid bubbles, and the carbon nanotubes was adding with different weight percentage (2, 3, 4, 5) wt% gradually into the mixture and stirring in order to obtain homogeneity for a period (8-10) minutes. The mixture were then poured into the molding with dimensions (120x120x6) mm and left for a period of (72) hours at room temperature to complete the curing process. Specimens were then extracted from the molding and heat treated in oven at (50 ^oC) for a period of (4) hours. All specimens were then cut into a diameter of (40mm) and a thickness of (6mm) according to standard method for thermal conductivity test as shown in Fig. 1.

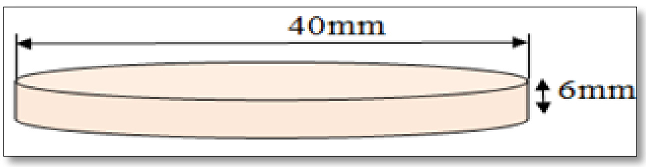

Fig. 1: Dimension of thermal conductivity test specimens.

Results and discussion

1. Thermal conductivity results for Ep/MWCNTs composites in natural condition

Thermal conductivity (k) measurements for all specimens in natural condition (before immersion) performed according to Lee's disk method. Thermal conductivity values were calculated according to Eqs. (2) and (3). The experimental results shown in Table 3. From Table 3 it is noted that thermal conductivity (k) increases with increasing wt% of MWCNTs as shown in Fig. 2, this behavior agrees with results [10, 12, 13, 17].

Table 3: Thermal conductivity values of Epoxy/MWCNTs composites.

Composites	Thermal Conductivity (W/m.k)	
	Natural Condition	After Immersion
Epoxy (pure)	0.271	0.233
Epoxy+2wt% MWCNTs	0.378	0.345
Epoxy+3wt% MWCNTs	0.398	0.378
Epoxy+4wt% MWCNTs	0.459	0.437
Epoxy+5wt% MWCNTs	0.559	0.528

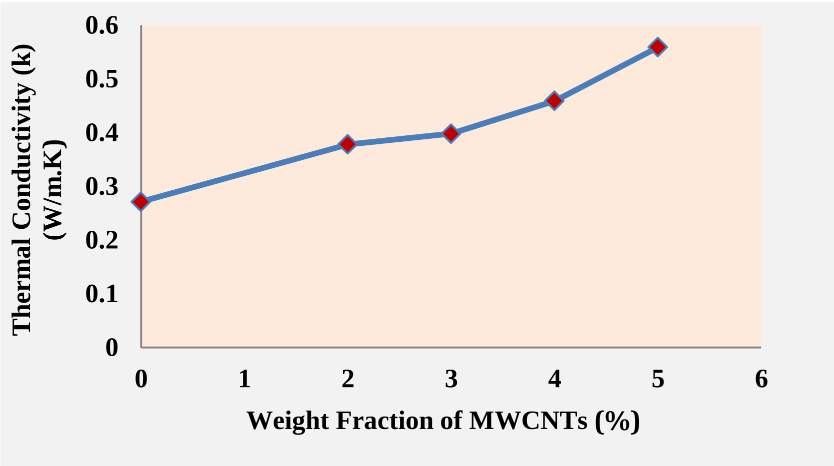

Fig. 2: Variation thermal conductivity (k) with weight fraction of MWCNTs in natural condition.

Reason increasing of the thermal conductivity with increasing filler content due to that carbon nanotubes had a very good thermal conductivity [13]. The theoretical axial thermal conductivity of CNT can reach 3000W/m.k, which is about 10000 times greater than thermal conductivity of epoxy resin [17]. Also the modification of epoxy resin matrix with CNTs might be caused the decrease in the mean distance among adjacent chains and hence to increase the elastic constants caused by the intermolecular interaction as a result, thermal resistant was decreased and therefore thermal conductivity increased [12,18].

From Table 3 it is noted that the thermal conductivities of epoxy/MWCNTs nanocomposites were low compared with expectations from the intrinsic thermal conductivity of CNTs, due to the large interfacial thermal resistance between the CNT and the surrounding epoxy matrix, which hinders the transfer of phonon dominating heat conduction in epoxy and CNT [9].

2. Thermal conductivity results for Ep/MWCNTs composites after immersion

The experimental results of thermal conductivity measurement after immersion in sodium hydroxide solution (NaOH) has normality (0.3N) for a period of (15) days at laboratory temperature shown in Table 3. From Table 3 it is noted that thermal conductivity (k) increases with increasing weight ratio of MWCNTs as shown in Fig. 3.

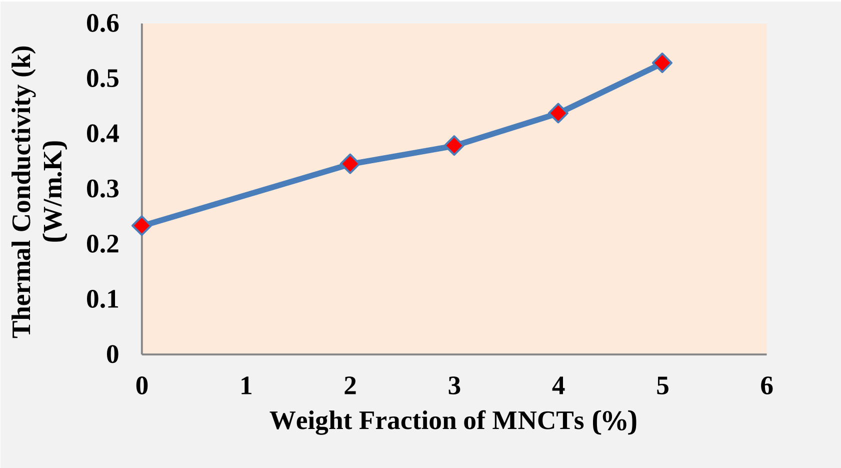

Fig. 3: Variation thermal conductivity (k) with weight fraction of MWCNTs after immersion.

The immersion of samples in base solution (NaOH) decreased thermal conductivity values for all samples compared to thermal conductivity values in natural condition as shown in Fig. 4, because of penetration of the base solution through the interface area and cracks that occur during the molding process work to breakdown bonds that act as a heat transfer carrier through the sample [19].

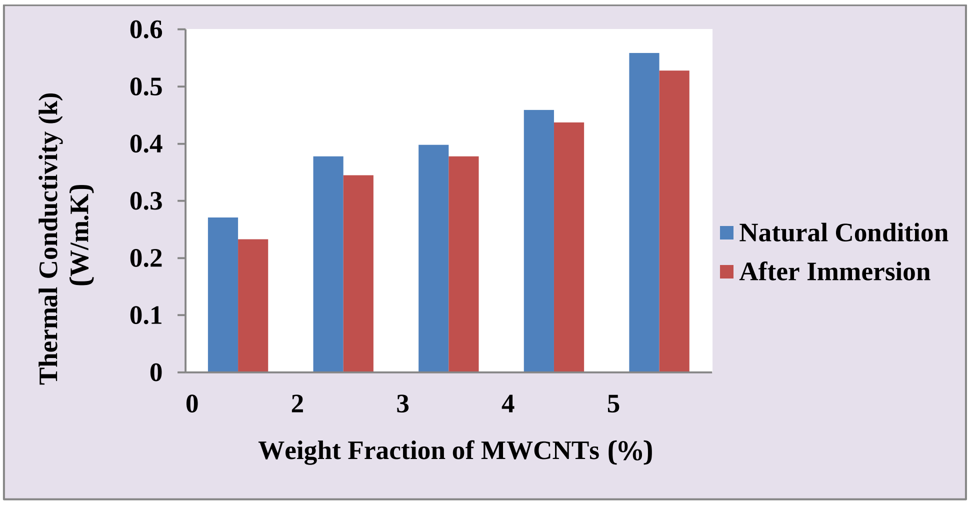

Fig. 4: Comparison between thermal conductivities in natural condition and after immersion for epoxy/MWCNTs composition.

Conclusions

In this study, MWCNTs used as a filler in epoxy resin. Five samples with different weight fractions (0, 2, 3, 4, 5) wt% of MWCNTs were made. The results showed the epoxy composites filled with a different weight fraction of MWCNTs give better thermal properties than pure epoxy, because the (CNTs) have a good thermal properties. It is found that thermal conductivity increased linearly with increase wt% of MWCNTs in natural condition and after immersion. Immersion of samples in base solution (NaOH) of (0.3N) for (15days) led to decrease thermal conductivity values for all samples compared to thermal conductivity values in natural condition (before immersion).

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