Journal of Engineering Sciences, Assiut University, Vol. 39, No 5, pp. 1055-1068, September 2011

ADVANCED MODEL FOR PREDICTING DIELECTRIC PROPERTIES OF NANOCOMPOSITE INDUSTRIAL MATERIALS

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(Received May 17, 2011 Accepted June 27, 2011)

This research studies the dielectric properties of nanocomposites, where each embedded spherical inclusion is surrounded by an inhomogeneous interphase, as well as the effects of inhomogeneous interphase on the bulk modulus of composite containing spherical inclusions. The modified model has been shown towards based engineering of optoelectronic packaging materials of dielectric constant modeling. The properties of composite materials of the new nanocomposite industrial materials have been developed in which spherical inclusions are embedded in a matrix of some kind. Different fitting models have been investigated for new industrial materials and improved the accuracy of their properties. The size of the spherical inclusion acts as the reinforcing phase has a major effect on the dielectric properties of composite industrial materials. Therefore, with the introduction of nanoparticles as the preferred reinforcing phase for some composites, the interphase has a major effect on its dielectric properties.

***KEYWORDS**: Dielectric Properties, Nano-Composite, Industrial Materials.*

1. INTRODUCTION

Over the recent years particulate composites have received much attention particularly with the introduction of nanoparticles. Nanoparticles offer improved mechanical, electrical, and thermal properties of composites at relatively low concentrations. One of the important properties of composites in general is their dielectric properties which have been studied extensively [1-4]. The dielectric properties of composites play an important role in areas such as microelectronic and optoelectronic packaging materials [1].

It has long been known that an interphase region forms around each inclusion within the composite material [2]. With the existence of the interphase region, some researchers have gone on to consider this region as being a homogeneous region with constant properties [3]. However, current research tends to suggest that the properties of the interphase would best be modeled not by a constant but by a smooth variation in properties [4]. Such a material is called inhomogeneous or a functionally graded material [5]. There have been a variety of papers that have modeled the mechanical, electrical, and thermal properties of the interphase as inhomogeneous [6–7]. More recently however, research tends to suggest that the dielectric properties of the interphase are also inhomogeneous, varying with respect to the radial distance from the centre of the spherical inclusion [8-10]. Such an inhomogeneous transition is due to the bonding mechanisms occurring in the space between the inclusion and matrix.

A controlled design of the spatial varying property also enables one to control the overall property of composites [9]. Results for the dielectric constant have been published for two-phase composites in which perfect bonding is assumed to exist between the inclusion and the matrix. The results are from Maxwell-Garnett theory [10] with the same result derived later by using the composite spheres assemblage model [11]. This same result can also be used for the electrical and thermal conductivity, magnetic permeability and diffusivity, provided that the spherical inclusions and matrix are isotropic. There has been a first principles approach developed in [12] to find the effective dielectric response of composites with a dilute suspension of graded spherical particles. Vo and Shi measured the dielectric properties of composites as a function of inclusion concentration using a proposed theoretical model based on effective medium theory [13, 14]. The dielectric property of composites and its dependence on the filler concentration is taken into account in their model. Therefore, their model is valid overall volume fractions and showed good agreement with experimental results.

In this paper it is shown that the equations derived using the Maxwell-Garnett mixing rule [15-19]. A law concentration of suspended inclusions since the interaction among the inclusions has neglected in the construction of these models. The equations derived in this paper are applied to three-power law profile PLP, which model the inhomogeneity of the interphase. A way to incorporate the inhomogeneous model with Vo and Shi's homogeneous model is therefore proposed [4]. The present work is a systematic theoretical investigation of the effective dielectric constant of polymer/filler nanocomposite materials and its dependence on the filler concentration. The polymer/filler interaction and the size of fillers, depending on dielectric constant ratio between filler and polymer matrix, and the degree of interaction between filler and matrix. The effective dielectric constant exhibits an extreme as a function of filler concentration.

2. ANALYTICAL MODEL STUDIED

This model studies the dielectric properties of composites, where each embedded spherical inclusion is surrounded by an inhomogeneous interphase. The size of the spherical inclusion which acts as the reinforcing phase has a major effect on the dielectric properties of composite industrial materials.

2.1 Inhomogeneous Interphase

The Maxwell-Garnett approximation of the dielectric constant of a composite ε_c consisting of isotropic spherical inclusions embedded in an isotropic matrix is given by:

$$\varepsilon_c = \varepsilon_m + \frac{c}{\frac{1}{\varepsilon_p - \varepsilon_m} + \frac{(1-c)}{3\varepsilon_m}} \quad (1)$$

Where ε_m is the dielectric constant of the matrix, ε_p is the dielectric constant of the inclusions, and c is their volume fraction.

To account for the presence of the interphase region consider Fig. 1 representing a small portion of interphase composite consisting of spherical particles all of radius a, surrounded by an annular interphase region of radius b, embedded in a surrounding matrix. This model the inclusion and interphase together as forming a new, effective spherical particle of radius b, with dielectric property denoted by ε_E. It shall be assumed throughout this work, that the inclusions are well spaced apart and that the interphase regions d_o not overlap. Once ε_E has been found, the dielectric constant of the composite can be easily calculated using (1) by replacing ε_p with ε_E, and $c=d_o(b^3/a^3)$, where d_o is the volume fraction of inclusion relative to all phases.

Now suppose that the properties of the interphase vary as continuous functions of x, where x represents the radial distance from the centre of the inclusion as shown in Fig. 1. That is, the dielectric constants of the interphase region are described by ε(x), where x Є [a, b]. Also assume that ε(x) is a smooth, bounded and continuous function. Consider a partition of [a, b] into n subintervals defined by: $a=x_o<x_1<x_2< \ldots.<x_{i-1}<x_i<\ldots. <x_{n-1}<x_n=b$. The lengths $\Delta x_1, \Delta x_2, \Delta x_3, \ldots, \Delta x_n$ of the subintervals $[x_o, x_1], [x_1, x_2], [x_2, x_3], \ldots, [x_{n-1}, x_n]$ associated with the partition, presently need not be the same. In each subinterval $[x_{i-1}, x_i]$, choose any point ξ_i, that is ξ_i Є $[x_{i-1}, x_i]$.

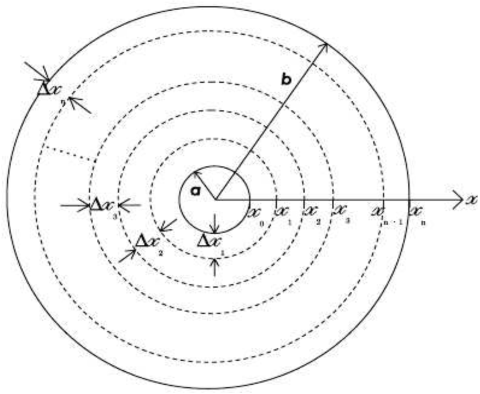


Fig. 1. Interphase consisting of n regions or layers

Then using the replacement method originally proposed by [2] for the elastic modules of composites, the effective dielectric constant ε_i of the inclusion up to the i^{th} layer can be approximated by:

$$\varepsilon_i = \varepsilon(\xi_i) + \frac{d_i}{\frac{1}{\varepsilon_{i-1}+\varepsilon(\xi_i)} + \frac{(1-d_i)}{3\varepsilon(\xi_i)}} \tag{2}$$

Where:

$d_i = \left(\frac{x_{i-1}}{x_i}\right)^3$, i Є {N:1≤ i ≤ n}, and ε_{i-1} is an approximation to the dielectric constant of the inner composite sphere that is calculated from the previous step. Our aim is to find the effective dielectric constant, ε_E, of the inclusion and whole interphase region which would be given by:

$$\varepsilon_E = \lim_{n\to\infty} \varepsilon_n \tag{3}$$

Where, ε_n is found by solving the recurrence relation (2).

The effective dielectric constant of the inclusion and interphase could be expressed according to as:

$$\varepsilon_E(b) = \frac{\varepsilon_p S(b)+T(b)}{\varepsilon_p U(b)+V(b)} \tag{4}$$

The above equations are useful because we are able to model the interphase inhomogeneity by smooth, bounded and continuous functions of x as opposed to using a discontinuous step like graded interface. Also, the above Equ's are applicable to any arbitrary profile for the interphase region. The present model can be applied to arbitrary graded profiles and is exact for spherical particles.

2.2 Power Law Profile PLP

That profile is used to determine the value of S(x), U(x), T(x), and V(x) at a specific radius. Suppose the dielectric properties of the interphase region vary according to the power law function given by:

$$\varepsilon(x) = \varepsilon_m J \left(\frac{a}{x}\right)^P \quad (5)$$

Where J represents the dielectric constant at the surface of the inclusion relative to that of the matrix while the constant P represents the rate at which the dielectric properties change with respect to x. Note that J is real and positive by definition while the constant P is real but may be either positive or negative. Also by using a fixed interphase thickness it is assumed that at the boundary between matrix and interphase, i.e. at x=b, that $\varepsilon(b)=\varepsilon_m$ and at x=a , have $b=aJ^{1/P}$, and $J=\varepsilon(a)/\varepsilon_m$. P may be chosen so that the interphase thickness is a certain percentage of the inclusion radius a, the interphase is assumed to have a thickness which is 30% of the radius of inclusion.

The solving of S(x), U(x), T(x), and V(x) is give by:

$$S(x) = Ax^{\lambda_1} + Bx^{\lambda_2} \quad (6)$$

$$U(x) = \frac{1}{\varepsilon_m J a^P}\left\{\left(\frac{\lambda_2}{2}+1\right)Ax^{\lambda_1+P} + \left(\frac{\lambda_1}{2}+1\right)Bx^{\lambda_2+P}\right\} \quad (7)$$

Where:

$A = \frac{1}{a^{\lambda_1}}\left(\frac{\lambda_2+2}{\lambda_2-\lambda_1}\right)$, and $B = \frac{1}{a^{\lambda_2}}\left(\frac{\lambda_1+2}{\lambda_1-\lambda_2}\right)$

Similarly:

$$T(x) = Ax^{\lambda_1} + Dx^{\lambda_2} \quad (8)$$

$$V(x) = \frac{1}{\varepsilon_m J a^P}\left\{\left(\frac{\lambda_2}{2}+1\right)Cx^{\lambda_1+P} + \left(\frac{\lambda_1}{2}+1\right)Dx^{\lambda_2+P}\right\} \quad (9)$$

Where:

$C = \frac{1}{a^{\lambda_1}}\left(\frac{2\varepsilon_m J}{\lambda_2+\lambda_1}\right) B = \frac{1}{a^{\lambda_2}}\left(\frac{2\varepsilon_m J}{\lambda_1+\lambda_2}\right) \lambda_1 = \frac{-(P+3)+\sqrt{P^2-2P+9}}{2}$, and

$\lambda_2 = \frac{-(P+3)-\sqrt{P^2-2P+9}}{2}$

2.3 Homogeneous Interphase Model

The Maxwell-Garnett dilute concentration solution for the dielectric constant is given by expression (1). Those have been able to manipulate this expression using the replacement method in order to account for an inhomogeneous interphase region surrounding each inclusion. That is, the mapping of the inclusion and surrounding inhomogeneous interphase onto an effective spherical particle of identical size with dielectric constant denoted by $\varepsilon_E(b)$. Once it has been found $\varepsilon_E(b)$ for an inhomogeneous interphase, a constant value ε_i for the dielectric constant of the interphase can be determined by doing a reverse mapping as shown in Fig. 2 that is, the mapping of a homogeneous sphere of radius b onto a two-phase sphere of identical size to determine the value of ε_i by:

$$\varepsilon_E(b) = \varepsilon_i + \frac{\left(\frac{a^3}{b^3}\right)}{\frac{1}{\varepsilon_p-\varepsilon_i}+\frac{\left(1-\frac{a^3}{b^3}\right)}{3\varepsilon_i}} \quad (10)$$

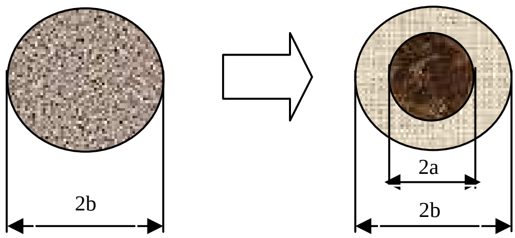


Fig. 2. A mapping of a homogeneous particle consisting of inclusion and interphase onto a two-phase composite

Thus, for an inhomogeneous interphase, the Vo and Shi method gives us a way of finding the equivalent homogeneous property of the interphase. Since it is know what the equivalent homogenous property of the interphase is, this result may be incorporated into other existing three-phase models, which assume a homogeneous interphase surrounding each inclusion. Therefore propose here a way of fusing two different models together, an inhomogeneous and a homogeneous interphase model. This joining process is called the fused model. For instance, the value ε_i calculated from Eq. (10) can be used in the Vo and Shi [4] model. The advantage of using the Vo and Shi model is that full volume fraction packing of spherical inclusions is allowed and the size of the interphase region may also vary as a function of inclusion concentration. Therefore, the Vo and Shi model allows us to account for this phenomena whereas the inhomogeneous interphase model does not. According to the Vo and Shi model, the dielectric constant of a particulate composite is given by:

$$\varepsilon_c = \frac{h+2l}{h-l} \quad (11)$$

Where:

$$h = \left\{1 + 2\frac{(\varepsilon_m-\varepsilon_i)(\varepsilon_i-\varepsilon_p)}{(2\varepsilon_m+\varepsilon_i)+(2\varepsilon_i+\varepsilon_p)}\frac{a^3}{b^3}\right\} - \left\{2\frac{(\varepsilon_m-1)(\varepsilon_m-\varepsilon_i)}{(\varepsilon_m+2)(2\varepsilon_m+\varepsilon_i)}\frac{b^3}{c^3}\right\} - \left\{2\frac{(\varepsilon_m-1)(\varepsilon_m+2\varepsilon_i)(\varepsilon_i-2\varepsilon_p)}{(2\varepsilon_m+2)(2\varepsilon_m+\varepsilon_i)(2\varepsilon_i+\varepsilon_p)}\frac{a^3}{c^3}\right\}$$

$$l = \left\{\frac{(\varepsilon_m-1)}{(\varepsilon_m+2)}j - \frac{(2\varepsilon_m+1)n}{(\varepsilon_m+2)(2\varepsilon_m+\varepsilon_i)}\frac{b^3}{c^3}\right\}$$

$$j = \left\{1 + 2\frac{(\varepsilon_m-\varepsilon_i)(\varepsilon_i-\varepsilon_p)}{(2\varepsilon_m+\varepsilon_i)+(2\varepsilon_i+\varepsilon_p)}\frac{a^3}{b^3}\right\}, \text{ and } n = \left\{(\varepsilon_m-\varepsilon_i) + \frac{(\varepsilon_m+2\varepsilon_i)(\varepsilon_i-\varepsilon_p)}{(2\varepsilon_i+\varepsilon_p)}\frac{a^3}{b^3}\right\}$$

The subscripts m, i and p stand for matrix, interphase and particle inclusion, respectively. The parameters a and b are as defined in inhomogeneous interphase model while the parameter c represents the radial distance from the centre of the inclusion to the outer boundary of the matrix phase of a representative composite sphere. The parameters a, b and c are related to each other through the parameters k and d_o where k is the interphase volume constant and d_o is the volume fraction of filler, that is:

$$\frac{a^3}{b^3} = \frac{(1+kd_0)}{(1+k)}, \frac{a^3}{c^3} = d_o, \text{ and } \frac{b^3}{c^3} = d_o\left\{1 + k\frac{(1-d_0)}{(1+kd_0)}\right\} \quad (12)$$

It is important to note that if the interphase volume constant k in Eq. (11) is set to zero, that is, k=0, their model tends to the Maxwell-Garnett approximation given by Eq. (1). As a result of this, if ignore Eq. (12) and allow b = constant × a, then under the mapping Eq. (10), the Vo and Shi model given by Eq. (11) converges to inhomogeneous interphase model. Therefore, this model and the inhomogeneous interphase model are the same when the size of the interphase remains fixed over all filler concentrations.

3. NANO-FILLERS AND POLYMERS FOR INDUSTRIAL MATERIALS

Fumed Silica is one of the most important fillers used for insulating materials, integrated circuits, electric components, conductors, and many other applications. Clay is a very cheap filler used in adhesives, protective coatings, traffic paint, joint compounds, plastics, cables and many other applications. Also, Carbon Black, Barium Titanate, and Zinc Oxide is used. Three nano-fillers are selected in this paper; Carbon Black is a one of the most common conductive fillers, which is relatively inexpensive, and it is providing an excellent electric conductivity applications, Barium Titanate, is most often found used as a thermistor e.g. in thermal switches, in capacitors, and in the pure form it is an electrical insulator, Finally, Zinc Oxide is inexpensive, and easy to prepare, and products are also suited to electronics applications such as capacitors, and electrophotography [7-9].

Epoxy Resin, is a thermosetting epoxide polymer that cures when it has been mixed with a catalysing agent or hardener. It has excellent adhesion, chemical and heat resistance, mechanical strength and electrical insulating properties. Many applications for Epoxy-based materials include coatings, adhesives, industrial tooling, electrical and electronic materials especially in generator ground wall insulation, medium and high voltage insulations. Other, selected industrial polymers in this works are Polyphenylene Oxide PPO, Polyimide PI, and Low Density Polyethylene LDPE. PPO is high-performance polymer, and an engineering conducting thermoplastic. The applications of PI include electrical fittings, TV components, and calculator cases. LDPE is a cheap thermoplastic polymer used for cable covering, core in UHF cables. PI film is used in capacitors, as cable insulation, as a coating for electrical components, and printed circuit boards. Also, PMMA is a thermoplastic having stiffness, and arc resistance. PMMA is used in microelectronic applications [10-14].

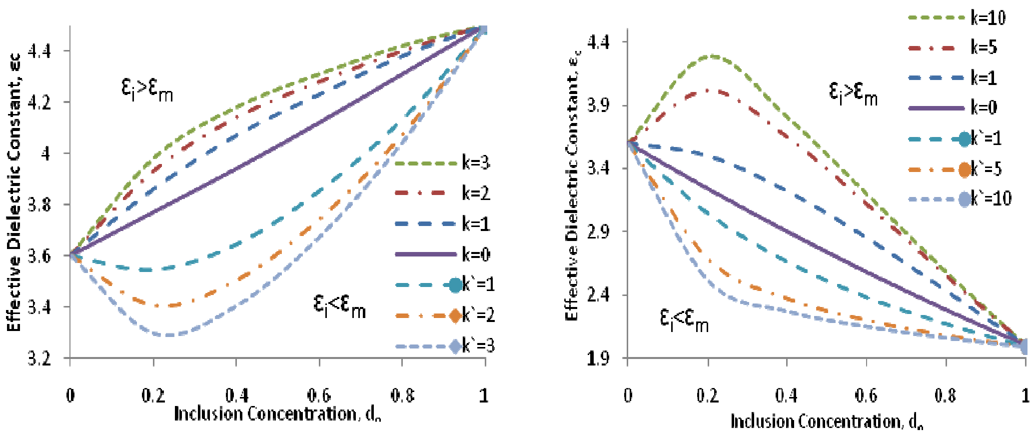
4. RESULTS AND DISCUSSIONS

The effective dielectric constant is a functional of the following parameters such as interphase volume constant k, interphase thickness constant x, and rate the dielectric properties to interphase thickness P, which have been chosen the properties of the interphase and varied those of the inclusion to the matrix. The effects of these parameters on the effective dielectric constant have been studied on both conductive nanocomposite (Epoxy with Fumed Silica) materials, and insulation nanocomposite (Epoxy with Clay). In addition, it can be investigate the fused model on the different other composites to specify the difference between the various values of the dielectric constant of the polymers and the dielectric constant of the inclusions. And so, the effect of interphase thickness on the interphase dielectric constant has been discussed.

4.1 Effect of Interphase Volume Constant k, on the Effective Dielectric Constant

Figure 3 represents the variation of the effective dielectric constant ε_c with the inclusion volume concentration do at different values of interphase dielectric constant. Fig. 3a shows that ε_c increases with the increment of d_o for Epoxy with Fumed Silica. When ε_i is larger than ε_m the effective dielectric constant increases with the increment of the interphase dielectric constant, and when ε_i is smaller than ε_m, the effective dielectric constant decreases with the increment of the interphase dielectric constant. The value of ε_i can be controlled by changing the interphase thickness x, where use the following values, at x=0.1, $\varepsilon_i>\varepsilon_m$ and at x=3, $\varepsilon_i<\varepsilon_m$.

Figure 3b shows that ε_c decreases with the increment of d_o for Epoxy and Clay composite. When ε_i is larger than ε_m the effective dielectric constant increases with the increment of the interphase dielectric constant, but when ε_i is smaller than ε_m, the effective dielectric constant decreases with the increment of the interphase dielectric constant. Data results are use the following values, x=1, $\varepsilon_i>\varepsilon_m$ and at x=0.1, $\varepsilon_i<\varepsilon_m$. The best value of k can be chosen to give the minimum value of the effective dielectric constant and so, with respect to experimental fabrication the spicing.

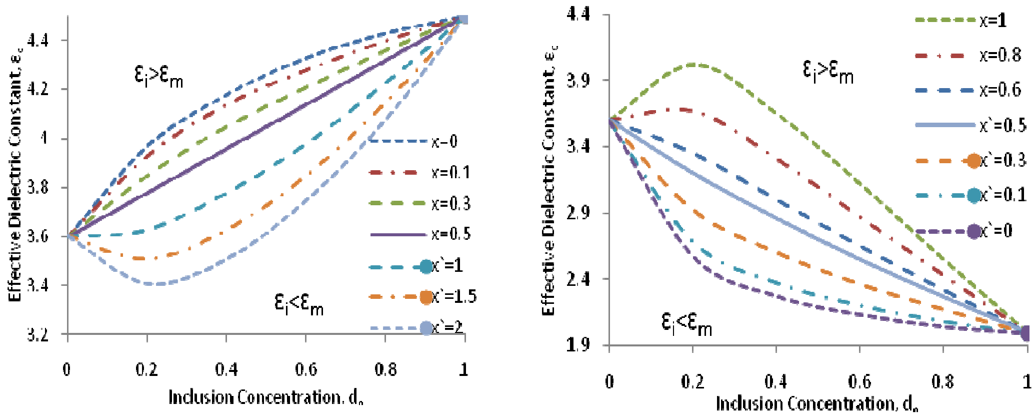


(a) Epoxy with Fumed Silica composite (b) Epoxy with Clay composite

Fig. 3. Effective dielectric constant for various composite with varying interphase volume constant, k

4.2 Effect of Interphase Thickness, x on the Effective Dielectric Constant

Figure 4 shows the variation of the effective dielectric constant ε_c with the inclusion volume concentration d_o at different values of interphase thickness x with two cases for nanocomposite. Figure 4a shows that for Epoxy with Fumed Silica composite, the effective dielectric constant ε_c increases with the increment of the inclusion volume concentration d_o. Also, it can be seen that at the values of x that make $\varepsilon_i>\varepsilon_m$ and $\varepsilon_i<\varepsilon_m$ the effective dielectric constant decreases with the increment of the interphase thickness. Figure 4b shows that, for Epoxy with Clay composite εc decreases with the increment of do, and at the values of x that make $\varepsilon i>\varepsilon_m$ and $\varepsilon i<\varepsilon_m$ the effective dielectric constant increases with the increment of the interphase thickness.



(a) Epoxy with Fumed silica composite (b) Epoxy with Clay composite

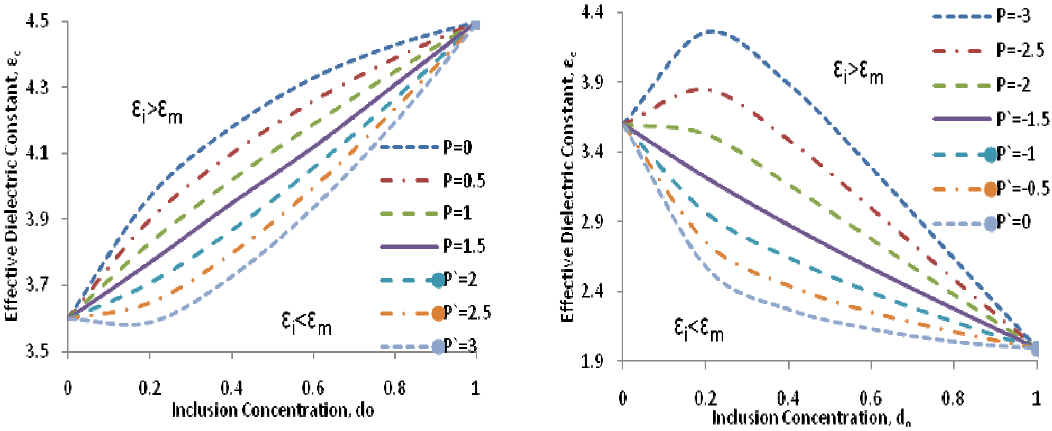
Fig. 4. Effective dielectric constant for various composites with varying interphase thickness x

4.3 Effect of Rate the Dielectric Properties to Interphase Thickness, P on the Effective Dielectric Constant

Figure 5 shows the variation of the effective dielectric constant ε_c with the inclusion volume concentration d_o at different values of rate at which the dielectric properties change with respect to interphase thickness or called P. Figure 5a shows that, Epoxy with Fumed Silica composite ε_c increases with the increment of d_o, and $\varepsilon_i>\varepsilon_m$ and $\varepsilon_i<\varepsilon_m$ occurs only with the positive values of P, while, Fig. 5b for Epoxy with Clay composite, ε_c decreases with the increment of d_o, and when $\varepsilon_i<\varepsilon_m$ and $\varepsilon_i>\varepsilon_m$ occurs only with the negative values of P. Also, it can be seen that at the values of P that make $\varepsilon_i>\varepsilon_m$ and $\varepsilon_i<\varepsilon_m$ the effective dielectric constant decreases with the increment of the interphase thickness for Epoxy with Clay composite, but increased for Epoxy with Fumed Silica composite.

4.4 Effect of Nano-Fillers on Different Industrial Polymers

Figure 6 shows the effect of inclusion concentration on the effective dielectric constant for three different industrial polymers such as PI, PP, and LDPE filled with Carbon Black nano-fillers. Figure 6a shows the effective dielectric constant ε_c with the inclusion volume concentration d_o, for interphase volume constant k=2, Fig. 6b for interphase thickness constant x=1.5, and Fig. 6(c) for rate the dielectric properties to interphase thickness constant P=-2 respectively. For PI with Carbon Black composite, the effective dielectric constant has the largest decrease with the increment of inclusion concentration, while PPO with Carbon Black composite, the effective dielectric constant is the same value at all inclusion concentration.

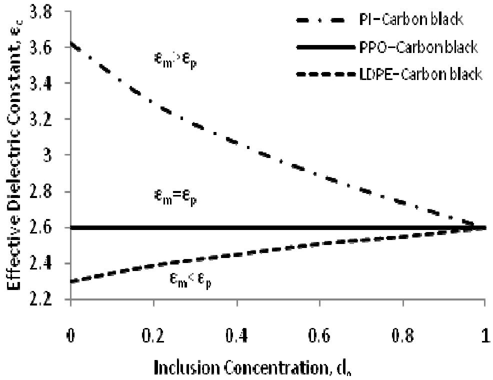


(a) Epoxy with Fumed silica composite (b) Epoxy with Clay composite

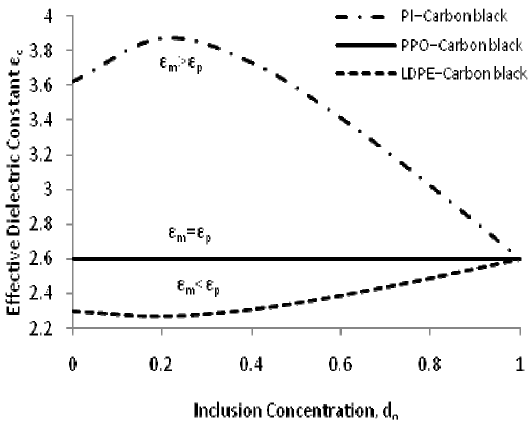
Fig. 5. Effective dielectric constant for various composites with varying values of rate the dielectric properties to interphase thickness P

For LDPE with Carbon Black composite, the effective dielectric constant has the smallest increase with the increment of inclusion concentration. At constant interphase thickness x, and rate of the dielectric properties to interphase thickness at parameter P, the same behavior occurs on interphase volume constant k, while PI with Carbon Black composite, the effective dielectric constant has the largest decrease from nearly 25% of the increment of inclusion concentration. Finally, the different effect of Carbon Black as an inclusion on each polymer according to the value of the dielectric constant, where it can be improved the dielectric properties of PI by decreasing its dielectric constant, and it can increase the conductivity of LDPE by increasing its dielectric constant, and it has no effect on PPO.

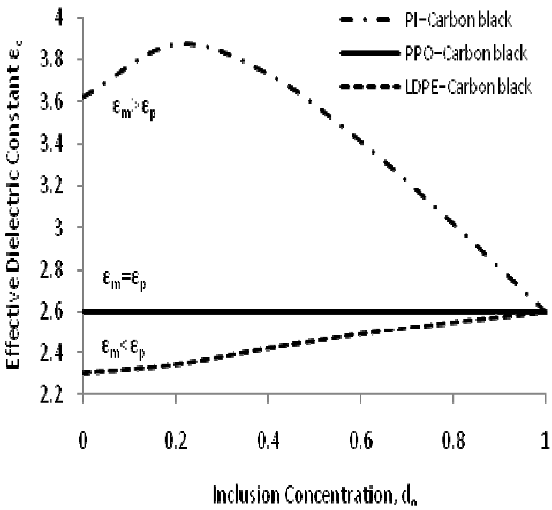
The effects of inclusion concentration on the effective dielectric constant for three nano-fillers such as Barium Titanate, Carbon Black, and Zinc Oxide with PMMA polymer has been shown in Fig. 7. Figure 7a shows the effective dielectric constant ε_c with the inclusion volume concentration do, for interphase volume constant k=2. Figure 7b for interphase thickness constant x=0.5, and Fig. 7c for rate the dielectric properties to interphase thickness constant P=5 respectively. It is cleared that, the different effect of each inclusion on the polymer according to the value of the dielectric constant of each inclusion, where Barium Titanate can increase the conductivity of PMMA by increasing its dielectric constant, and can improved the insulation properties of PMMA by decreasing its dielectric constant, but Carbon Black has no effect on PMMA.



(a) k=2

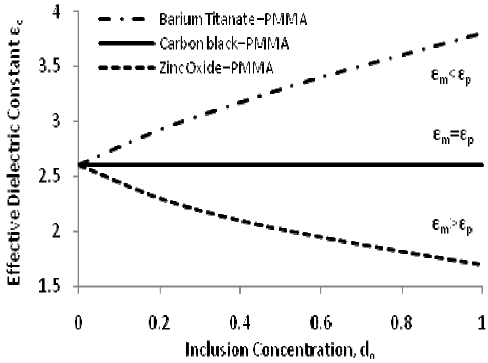


(b) x=1.5

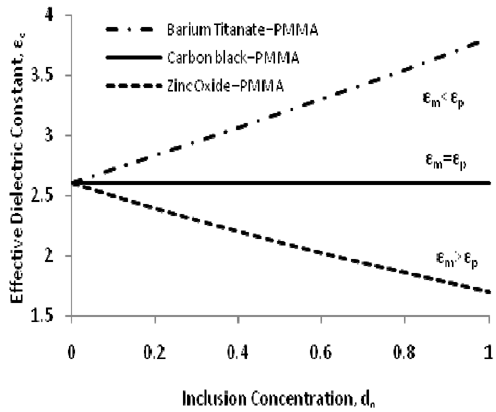


(c) P=-2

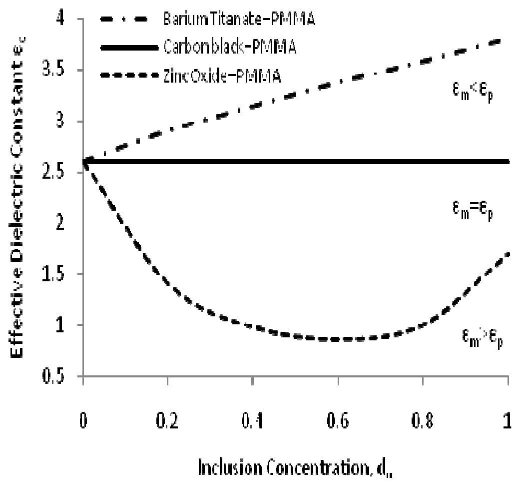
Fig. 6 Effects of inclusion concentration on the effective dielectric constant for three different industrial polymers



(a) k=2



(b) x=0.5



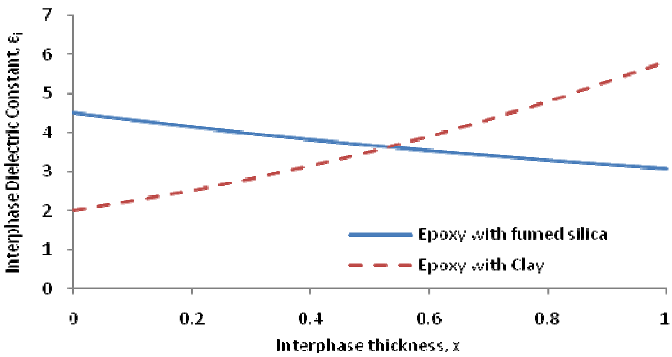
(c) P=5

Fig. 7 Effects of inclusion concentration on the effective dielectric constant for three different industrial nano-fillers

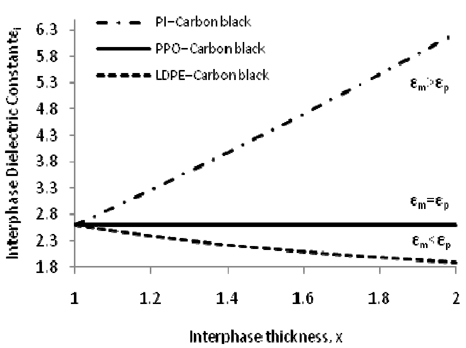
4.5 Effect of Interphase Thickness on the Interphase Dielectric Constant

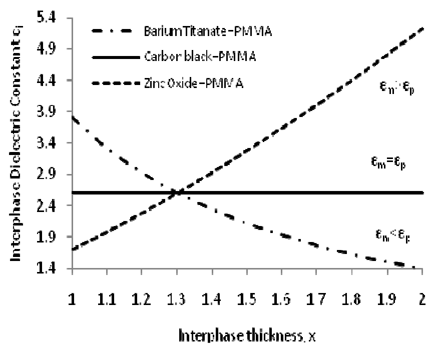
Figure 8 shows that the variation of the interphase dielectric constant with the interphase thickness x. For Epoxy with Fumed Silica composite, the interphase dielectric constant decreases with increasing interphase thickness x, while it can be noted that for Epoxy with Clay composite, the interphase dielectric constant increases with the increment of x as shown in Fig. 8a. Whenever, the three nanocomposites have the same interphase dielectric constant at thickness x=1.3, which represents the radius b of the inclusion and interphase, at x=1 represent the radius a of the inclusion the ε_i is equal to ε_P of each nanocomposite. The three polymers composites with Carbon Black nano-filler, for PI the interphase dielectric constant is increased linearly with the increment of interphase thickness, for PPO, the interphase dielectric is not change for all interphase thickness, and for LDPE the interphase dielectric constant is decreasing with the increment of interphase thickness as shown in Fig. 8b.

In another application, whatever, three composites have the same interphase dielectric constant at thickness x=1, which represents the radius a of the inclusion, also the ε_i is equal to ε_m of each composite as shown in Fig. 8c. It is noted, three nano-fillers composites with PMMA, Barium Titanate the interphase dielectric constant decrease with the increment of interphase thickness, but carbon black is the same value for all interphase thickness, and zinc oxide decrease with the increment of interphase thickness.



(a) Epoxy with Fumed Silica, and Clay composites





(b) Polymers with Carbon Black composites (c) Nano-fillers with PMMA composites

Fig. 8. The PLP for the dielectric constant of the inhomogeneous interphase region

5. CONCLUSION

The behavior of the effective dielectric constant with each parameter depends on the value of the dielectric constant of the inclusion, and the value of interphase dielectric constant. Nano-fillers of Clay and Fumed Silica have high effective parameters on the dielectric composite constant for increasing the insulation and the conduction of industrial materials. Low cost of Clay, and Fumed Silica fillers give the importance of new costless industrial materials by using these fillers for obtaining conducting or insulating industrial materials. It can be increased the insulation or conduction of the polymer by the same nano-filler with respect to the interphase thickness in the composite. Nano-fillers can be increasing or decreasing the effective dielectric constant of nanocomposite polymers with respect to the percentage of inclusion dielectric constant to matrix dielectric constant. Interphase dielectric constant is an effective parameter for controlling on effective dielectric constant of the nanocomposite, related to its thickness.

ACKNOWLEDGMENT

The present work was supported by the Science and Technology Development Fund (STDF), Egypt, Grant No: Project ID 505.

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تحسين السماحية لمركبات النانو من بوليمرات المواد الصناعية باستخدام نموذج قوي التداخل

نظرا لاهمية حيز التداخل والذي يحدث نتيجة لإعاقة حبيبات النانو لحركة جزيئات البوليمر، فان هذا البحث يتناول دراسة تأثير حيز التداخل علي عدد من المواد المركبة مع تغيير نوع الحبيبات داخل المركب إعتمادا علي سماحية كلا من البوليمر والحبيبات ومجال التداخل ونسب كلا منهم داخل المركب. كما يقدم البحث خصائص المواد المركبة العازلة والموصلة وأثر التداخل المتغير والتي تحتوي على تعديل نموذج هندسي قائم على المواد المركبة العازلة والموصلة. وكذلك خصائص المواد المركبة من المواد الصناعية الجديدة التي تم تطويرها للحصول علي اعلي اداء كهربي لها. وقد تم استنتاج النماذج الرياضية المختلفة لتركيب المواد الصناعية الجديدة لتحسين خواصها. كما وضح البحث ان مساحة تداخل حبيبات النانو لديها تأثير كبير على خصائص المواد العازلة والموصلة الصناعية المركبة.