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A study of the effect of silica particles addition on some physical properties of PVC as a packaging material

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Abstract

In this work, varying compositions of SiO_2 micro filler were added with the Polyvinyl Chloride (PVC) and samples have been prepared using film casting technique. The results have been analyzed and compared for PVC samples with (1 wt%, 3 wt%, 5 wt% and 10 wt%) SiO_2 micro filler. Mechanical characteristics such as tensile strength, elongation at break and Young`s modulus were measured for all the samples, where the tensile strength was increased from 8.39 Mpa for purified PVC to 16 Mpa for 3% SiO_2/PVC composite. Also, thermal conductivity measurement values illustrated that composite materials have a good thermal insulation at 10 wt. %, thermal conductivity was decreased from 0.1684 W/m. K for PVC to 0.1310W/m. K at 10% SiO_2/PVC composite. Absorptivity test was also carried out for these samples, the results of this study proved that PVC and SiO_2-PVC composites have low diffusion coefficients ranging from (10^{-13}- 10^{-10} m^2/s). Similarly, the dielectric properties like dielectric constant, loss factor, resistance, and volume resistivity were performed; the dielectric constant was increased from 2.1039 for PVC to 3.658 for 3% SiO_2/PVC composites, while the dielectric loss factor was decreased from 0.0144 for PVC to 0.0137 for 5%SiO_2/PVC composite. The values of resistance were increased from 17259.99(Ω) for purified PVC to 29185.75(Ω) for 10% SiO_2/PVC composites. Volume resistivity was increased from 0.3794 x10^9 (Ω. cm) for PVC to 0.5179x10^9 (Ω. cm) for 10% SiO_2/PVC composites. FTIR spectroscopy was employed for all PVC-composite samples and its results were investigated, there are systematic increases in absorbance intensity spectra with SiO_2 ratios attributed to good distribution of inorganic fillers (Symmetric increases). The microstructure and morphology of the prepared samples were investigated by using optical microscope. It can be observed that, the samples with (3% SiO_2/PVC) are glossy and smooth without agglomeration of (SiO_2) particles in (PVC) matrix. The results demonstrate that PVC-composite films prepared in this study show promising potential to achieve good materials for plastic packaging applications.

Key words

Silica, Physical properties, PVC, Plastic packaging, Polymer composites.

Article info.

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دراسة تأثير اضافة جسيمات السيلكا على بعض الخواص الفيزيائية للبولي فينيل كلورايد كمادة تعبئة و تغليف

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الخلاصة

في هذا البحث، اضيفت مكونات مختلفة من مالئات السليكا المايكروية الى البولي فينيل كلورايد وتم تحضير العينات بأستخدام تقنية صب الأفلام. و قد تم تحليل ومقارنة النتائج لعينات PVCعند (1 wt%, 3 wt%, 5 wt% and 10 wt%) من مالئات السليكا المايكروية. تم قياس الخصائص الميكانيكية مثل قوة الشد، الاستطالة عند الكسر، ومعامل يونك لجميع العينات، حيث زادت قوة الشد من 8.39 Mpa لمادة PVC الى 16 Mpa عند التركيز 3% SiO_2/PVC. ايضا تم تنفيذ اختبار الموصلية الحرارية حيث اظهرت النتائج ان متراكبات SiO_2/PVC تمتلك عزل حراري جيد عند التركيز 10% حيث انخفضت قيمة التوصيلية الحرارية من 0.1684 W/m. K لمادة PVC الى 0.1310W/m.K عند التركيز 10% SiO_2/PVC. ايضا اجري اختبار الامتصاصية لهذه العينات، اثبتت نتائج هذه الدراسة ان PVC ومتراكباته تمتلك معاملات انتشار واطئة تتراوح بين (10^{-13} - 10^{-10} m^2/s). وبالمثل اجري اختبار الخصائص العزلية: ثابت العزل الكهربائي، معامل الفقد، المقاومة، والمقاومة الحجمية، حيث ازدادت قيمة ثابت العزل الكهربائي من 2.1039 للPVC الى 3.658 لل 3%) SiO_2/PVC بينما انخفضت قيمة معامل الفقد من 0.0144 لل PVC الى 0.0137 (5%SiO_2/PVC) . وقد زادت قيمة المقاومة من 17259.99Ω لمادة PVC الى 29185.75 عند التركيز(10% SiO_2/PVC)، اما قيمة المقاومة الحجمية فقد زادت من 0.3794 x10^9 Ω. cm لمادة الPVC الى 0.5179 x10^9 (Ω. cm) عند التركيز(10% SiO_2/PVC). اجريت فحوصات (FTIR) الطيفية لمتراكبات ال (PVC) وتم تفسير نتائجها حيث اظهرت النتائج ان هناك زيادات منتظمة في شدة الامتصاص مع زيادة نسب (SiO_2) وهذا يعزى الى التوزيع المتجانس للمادة المضافة.ولقد تم الكشف عن التركيب البنيوي للعينات المحضرة بأستخدام المجهر الضوئي. حيث لوحظ ان العينات ذات التركيز (3%SiO_2/PVC) تمتلك سطوح صقيلة و ذات مظهر لامع تخلو من تجمعات الدقائق السليكونية. تظهر النتائج ان متراكبات ال PVC التي اعدت في هذه الدراسة تمتلك امكانيات واعدة كونها تتميز بخواص تلائم تطبيقات التعبئة والتغليف البلاستيكية.

Introduction

Packaging is one major field of application for plastic materials; it is a coordinated system of a techno-economic function for preparing goods for transport, distribution, storage, retail sale and end use, moreover optimizing the costs of delivering goods whilst maximizing sales and profits [1]. The basic function of all packaging materials is to protect, contain, carry and dispense a product, while other requirements were added as preserve and to measure, also to communicate and to display [2]. The overwhelming success of plastics as a packaging medium can be attributed to the range of properties including: they are inexpensive to produce, light in weight and bulk, important for shipping, can be flexible or rigid, the capability of taking any shape. They all allow permeation of atmospheric gases and vapors to some extent, these permanents include: water, vapor, oxygen, nitrogen and others which are significant for food, beverage and many other types of packaging [3].Packaging design and technology requires a specified knowledge of a wide range of polymeric properties, these include: "inherent" or physical characteristics (density, orientation and gas barrier properties), mechanical properties (strength and stiffness), thermal properties that involve the melting temperature, or chemical properties which include weather resistance and the solubility of a chemical in the polymer which is being used for the packaging [4]. Poly (vinyl chloride) (PVC) is one of the most common commodity plastics, which has been widely used in automobile, building construction, packaging fields including: films and sheets for packaging and thermoforming, clear and opaque bottles, food and non- food packaging, various containers for chemicals, clear blisters, and jar lid gasketing, because of its low cost, easy method of preparation, and the broadening of the properties range [5].Silica powder is one of the most widely used filler that exhibits the main role of enhancing both mechanical and thermal properties of the polymer composites. Polymer-SiO_2 composites have a technological importance in a variety of potential applications as electro chromic windows, full cells, chemical separation, electrochemical sensing and water treatment etc. [6]. PVC/SiO_2 composites has been studied by different approaches by different workers, R. H. Y. Subban and A. K. Arof [7] fabricated composite polymer electrolytes based on (PVC) with lithium trifluoro sulphonate $Li(F_3SO_3)$ as doping salts for different concentrations of silicone Di-oxide (SiO_2) as the inorganic filler. FTIR and X-ray diffraction studies show that complexation has taken place mainly in the crystalline phase. The effect of inorganic filler on the electrical conductivity of the composite polymer electrolytes was studied as a function of SiO_2 content and temperature. B. K. Deka and T. K. Maji [8] evaluated the effect of addition of nano-clay and SiO_2 on the properties of wood polymer composite. WPC treated with 3wt% each of clay and SiO_2 showed an excellent improvement in mechanical, thermal and flame retarding properties, while the decreasing of water uptake of WPC on incorporation of nano-clay and SiO_2 in WPC.C. P. Sugumaran [9] studied some dielectric and mechanical properties for composite materials by using PVC as a matrix which filled with a varying composition of nano SiO_2. The results have been analyzed and compared for PVC samples with 2.5wt%, 5wt% and 7.5wt% SiO_2 nano-filler. The additions of nano-fillers enhance the mechanical and electrical properties of PVC.N. Jon et al. [10] have prepared epoxidases natural rubber (ENR)/ Poly (Vinyl Chloride) (PVC) membranes filled with two types of silica fillers (microcrystalline silica powder) and (nano-silica) via simultaneous solvent exchange and evaporation of solvent technique. The chemical composition, morphology and chemical stability of the membranes were studied. Indeed, the mechanical properties of membrane improved with the addition of silica. The tensile strength increased from 10.6 Mpa to 17.8 Mpa and 14.5 Mpa for nano-silica and micro-silica filled membrane.

Experimental part

Materials

The following materials were used for preparation of polymer composite samples: a white powder of Poly (vinyl chloride) (PVC) was made in Korea (Hyundai Company) was used as a polymeric matrix. Silicone di-oxide micro-powder with a particle size diameter (1.112 µm) was used as ceramic filler for the polymer matrix. Cyclohexanone was used as a chemical solvent for dissolving PVC and its composites. Ethanol solvent as well as (CH_3COOH), (NaOH) solutions, and distilled water were used as penetrating mediums for PVC and its composites.

Synthesis of poly vinyl chloride composites

Polymer composite films of PVC and silica micro-particles of different compositions (1, 3, 5, and 10 wt. %) were prepared by solution casting method using Cyclohexanone as solvent. For the preparing of samples accurately weighed amount of SiO_2 particles (0.07, 0.21, 0.35, and 0.7 g) were dissolved separately in the solvent.

After allowing them to dissolve completely, the polymer solutions poured on to previously cleaned and dried glass petri-dishes, the solvent is evaporated at room temperature to form composite films; these films were peeled off from petri. All obtained films were semi-transparent, uniform in thickness, and free from air bubbles. Fig. 1 shows all the prepared samples involved, and Table 1 explains the thicknesses of these samples.

Table 1: Thicknesses of samples.

Polymer Systems	Thickness (mm)
PVC	0.25
1%SiO_2/PVC	0. 31
3%SiO_2/PVC	0.22
5%SiO_2/PVC	0.27
10%SiO_2/PVC	0.31

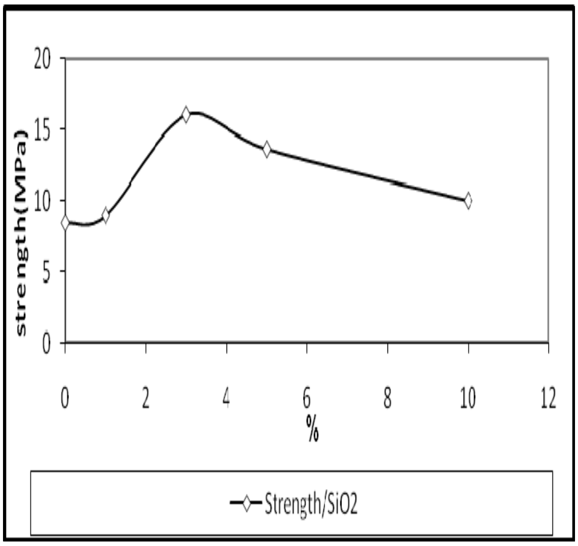


Fig. 1: Change in strength versus weight ratios.

Characterization of PVC-composites

1. Mechanical properties

Tensile properties (tensile strength, modulus of elasticity and percent elongation (%)) were evaluated using a tensile machine of (LARYEE-50 KN, China), with the crosshead speed of (5mm/min). The test was carried out according to ASTM D-638 standard test and calculated using Get Data software. Samples of films (12x60 mm) were taken for the determination of tensile properties. The modulus of elasticity and the tensile strength are given in the following equations respectively [11]:

$$\mathbf{E = \sigma/\epsilon} \qquad \mathbf{(1)}$$

where: E modulus of elasticity (MPa), ϵ strain, σ is the stress (MPa).

$$\sigma_{max} = F/A \qquad (2)$$

where: σ_{max} is the maximum tensile strength (MPa), F is force at failure, and A is a cross sectional area at break.

2. Thermal conductivity test

Lee`s disc instrument, manufactured by the Griffen and George Company, was used to calculate the thermal conductivity of the samples under test. The value of thermal conductivity is calculated by using the following equation [12]:

$$K\left(\frac{T_B-T_A}{ds}\right)=e\cdot\left(T_A+\frac{2}{r}\left(d_A+\frac{1}{4}ds\right)T_A+\frac{1}{2r}\cdot ds\cdot T_B\right) \qquad (3)$$

where:

K: the thermal conductivity coefficient (W/m. ^{o}C).

T_A, T_B and T_C: are the temperature of the disk (at A, B, and C) (^{o}C) respectively.

d_A, d_B and d_C: thickness of the disks A, B, and C respectively(mm).

d_S: thickness of sample (mm).

r: disk`s radius (mm).

e: The quantity of heat flowing through the cross sectional area of the specimen per unit time (W/m. ^{o}C), which is calculated from the following equation:

$$H=I\cdot V=\pi r^2\cdot e\cdot(T_A+T_B)+2\pi r\cdot e\cdot(d_A\cdot T_A+\frac{ds}{2}(T_A+T_B)+d_B\cdot T_B+d_c\cdot T_c \qquad (4)$$

where:

I: Current through the heater (Ampere).

V: Applied voltage (Volt).

3. Absorpitivity test

For this test, samples of 1 x 1 cm^2 dimensions were used. The original mass of samples was measured before sorption experiments using a sensitive electric balance (Denver Instrument) that measured reproducibility within 0.00001g. Four types of solutions were used for this measurement (distilled water, 0.5NCH_3COOH, 0.5N NaOH, and Ethanol solvents). According to the second Fickien law, the diffusion coefficients (D) for all samples are calculated by the relation [13]:

$$D = \pi (k\, t / 4\, M_m)^2 \qquad (5)$$

where:

k : is the slope straight line of the curves, which represent the relations between the weight gain% and √ time.

t: is the thickness of the samples.

M_m: is the apparent maximum water content (the saturation level).

4. Dielectric Test

Dielectric properties of PVC composites were determined by measuring the values of dielectric constant, volume, volume resistivity, and dielectric losses of film samples, at room temperature in the frequency range ($50\text{-}5*10^6$) Hz. Using (Impedance analyzer 4294 A) provided with Win Data and Win Fit software for experimental data visualization and treatment.

The volume resistivity (ρ) [14]:

$$(\rho) = R * A / l\ (\Omega\ .\ \mathrm{cm}) \qquad (6)$$

where:

R resistance measured (Ω), A area (cm^2), and *l* thickness of sample (cm).

The dielectric dissipation factor tan (ô)[15]:

$$\tan(\delta) = \varepsilon'' / \varepsilon' \qquad (7)$$

where:

ε″: the imaginary part of the permittivity (F/m).

ε′: real part of permittivity (F/m).

5. FTIR Study

The Fourier Transform Infra-Red Spectroscopy (FTIR) spectra of the samples were obtained using "Burker Tensor-27" FTIR spectrometer (Germany) in the range of 400 - 4000 cm^{-1}. The functional groups of the samples were then deduced.

6. Morphological Study

The morphology of PVC composite films was studied by using "Optical microscope" of Bell Company; with the investigation magnification was equal to (X100). The digitized images of the samples were recorded and studied.

Results and discussion

1. Mechanical behavior of PVC-Silica composites

The study of mechanical properties of polymer composites becomes vital to choose these materials for numerous applications. The mechanical properties of polymer systems depend on the intermolecular forces chain, stiffness, and molecular symmetry of polymer used to prepare composite [12]. In general, polymers have either a high degree of crystalinity, cross linking or rigid chain exhibit a high strength or low extendibility, thereby giving a high yield modulus, high stress at peak value, and low elongation value [16]. The enhancement in the mechanical properties was due to the good distribution of inorganic fillers in (PVC) polymer matrix [10]. From Fig. 1 it was found that an increment in tensile strength with SiO_2 content up to 3%, such improvement can be attributed to the hydrogen bonding between SiO_2 as filler particles and PVC as a polymer matrix as well as filler-polymer tethering, the increment in strength can also be attributed to the increasing in the ability of adhesion between the filler and the matrix lead to decrease the sliding between composites layers when applying stress in the composites [9, 17].

The general behavior of Young`s modulus was found depending on the elongation according to the filler contents, and the homogeneity of filler distribution in PVC matrix. Fillers can be considered as a solid phase with interfacial interaction between themselves [18, 19]. This behavior is explained in the two figures below. The results of mechanical study were listed in Table 2.

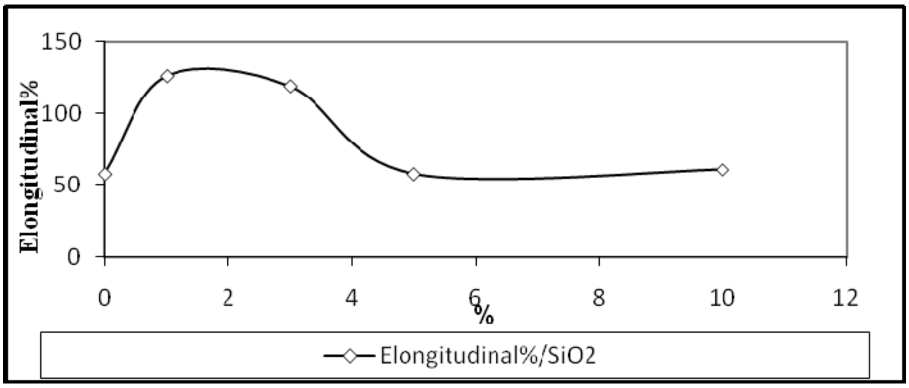


Fig. 2: Change in elongitudinal % with the silica compositions.

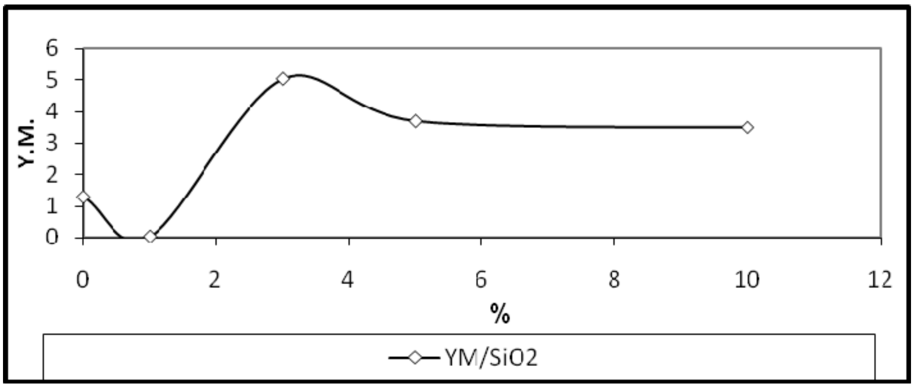


Fig. 3: Change in Young`s modulus with SiO_2 weight ratios.

Table 2: Main mechanical properties of polymer filled SiO_2 composites.

Silica`s Ratio	**Mechanical Properties**		
	Tensile Strength (MPa)	Elongation at Break (%)	Modulus of Elasticity (MPa)
0%	8.39E+00	5.77E+01	1.30E+00
1%	8.93E+00	1.26E+02	5.00E-02
3%	1.60E+01	1.19E+02	5.04E+00
5%	1.36E+01	5.77E+01	3.70E+00
10%	9.99E+00	6.07E+01	3.50E+00

2. Thermal conductivity behavior

Fig. 4 shows SiO_2 effect on the thermal conductivity of (PVC). The experimentally observed value of thermal conductivity for (PVC) is (0.1684) W/m. K at room temperature. This figure shows a decrease in thermal conductivity by SiO_2 loading. In amorphous polymers like (PVC) the thermal conductivity in the low temperature region (in the vicinity of room temperature) is controlled by the variation of phonon mean free path. For (PVC) the phonon mean free path is very small because of presence of numerous defects in the amorphous state at room temperature. Certain defects such as bend in chains, gab between two chains, chains of smaller length than others are created in the system during polymerization of the polymer [20].Thermal conductivity results were explained in Table 3.

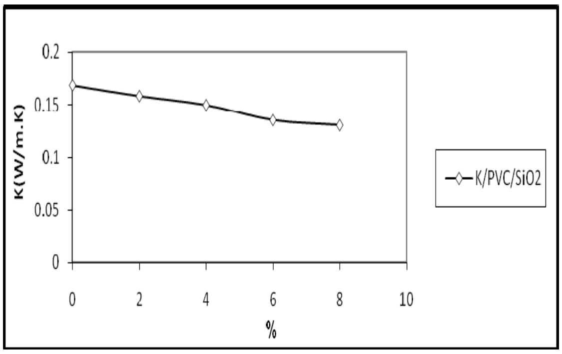


Fig. 4: The thermal conductivity variation curve of PVC micro-composites.

Table 3: Thermal conductivity values of polymer filled SiO_2 composites.

Silica`s Ratio	Thermal Conductivity (W/m. K)
0%	0.1684
1%	0.1584
3%	0.15
5%	0.1357
10%	0.1310

3. The diffusion studies of different types of liquid environments into PVC, and PVC composites:

3.1 Water absorption in PVC and its composites

Fig. 5 shows the kinetic of water penetration in the polymer systems involved. In the simplest case, water or solution enter the polymer systems without interacting with the molecular segment. This case can be represented by "Fick`s law", which assumes that the absorption is a diffusion process only driven by moisture concentration gradient [21, 22]. Decreasing in weight gain (%) up to 3%wt for (SiO_2/PVC) composites has been noticed; that was attributed to the PVC of higher sorption than PVC loaded systems, due to the flexible nature of the chain that creates more free volume in the matrix.

3.2 Acetic acid absorption in PVC and its composites

Fig. 6 shows the acetic acid diffusion in PVC, and PVC loading with SiO_2. The results proved that for SiO_2/PVC there was increasing in swelling and till they were more than (PVC) Figure 6illustrated that there was unsystematic changes of weight gain with SiO_2 loading ratios, but at 10%SiO_2/PVC was of the lower absorption [22, 23].

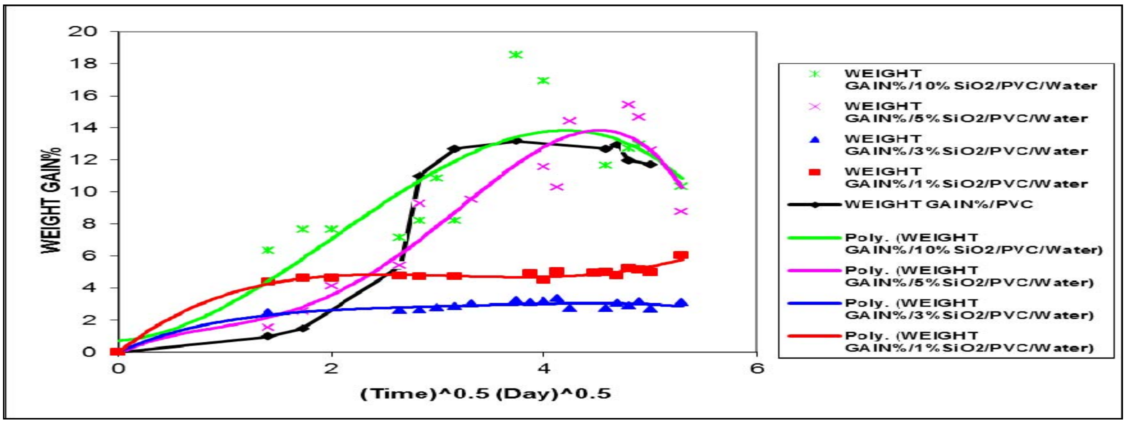


Fig. 5: Weight gain (%) of PVC &SiO_2/PVC composites in water as a function of square root of immersion time.

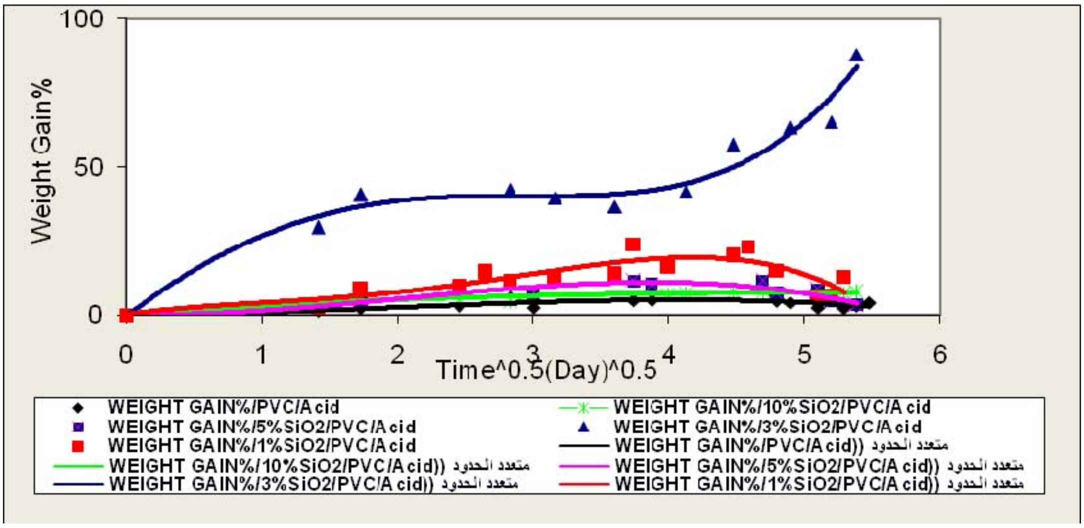


Fig. 6: Weight gain (%) of PVC & SiO_2/PVC composites in acid as a function of square root of immersion time.

3.3 Sodium hydroxide absorption in PVC and its composites

From Fig. 7 it was observed that unsystematic changes in weight gain by SiO_2 loading that reflected by the existence of some voids, and cracks after all cases especially with (NaOH). These defects may be related to penetrate of this solution into the structure of polymer systems more than the other liquids under work [22].

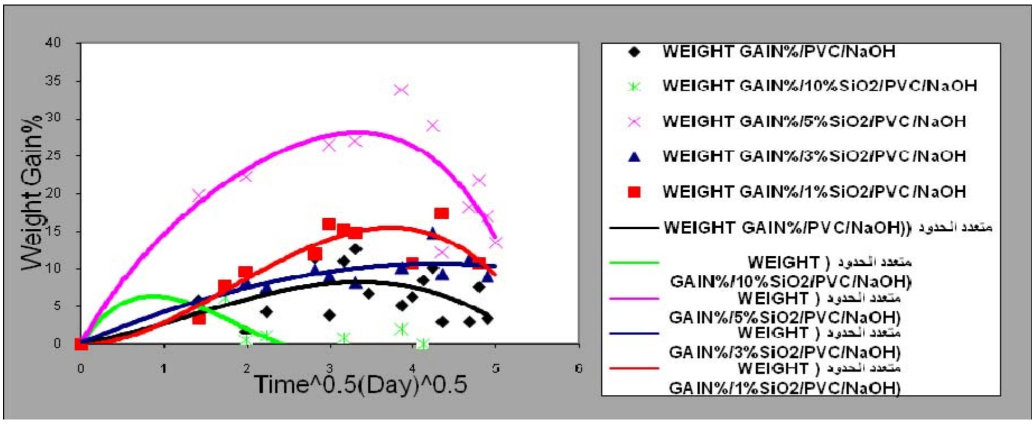


Fig.7: Weight gain (%) of PVC & SiO_2/PVC composites in NaOH as a function of square root of immersion time.

3.4 Ethanol absorption in PVC and its composites

Fig. 8 proved the functional relation of the weight gain (%) and $t^{1/2}$that reveals a good linearity in the initial stage. This implies that, ethanol migration from plastic modulus of the straight line is closely connected with the diffusion coefficients of the ethanol migration in this system. The effect of silica on barrier to diffusion of ethanol was studied at room temperature. It was found that there was reduction in solvent uptake at 10%SiO_2/ PVC but till it more than PVC uptake of one month period. It was attributed to the fine state of dispersion of SiO_2 particles. The increase in solvent uptake probably due to trapped air bubbles around large particle agglomerates [24].

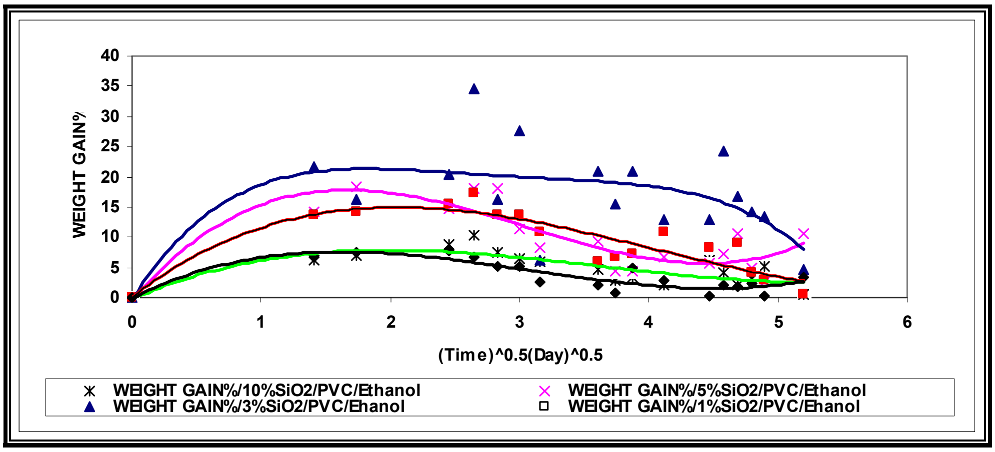


Fig. 8: Weight gain (%) of PVC & SiO_2/PVC composites in ethanol as a function of square root of immersion time.

Figs. (9-12) illustrate the results of diffusion coefficient of PVC, SiO_2/PVC composites at different concentrations; they demonstrate that PVC, SiO_2/PVC composites at selected concentrations can be used as containers for different solutions according to their low diffusion coefficients. Diffusion coefficients results of chemical solutions were explained in Table 4.

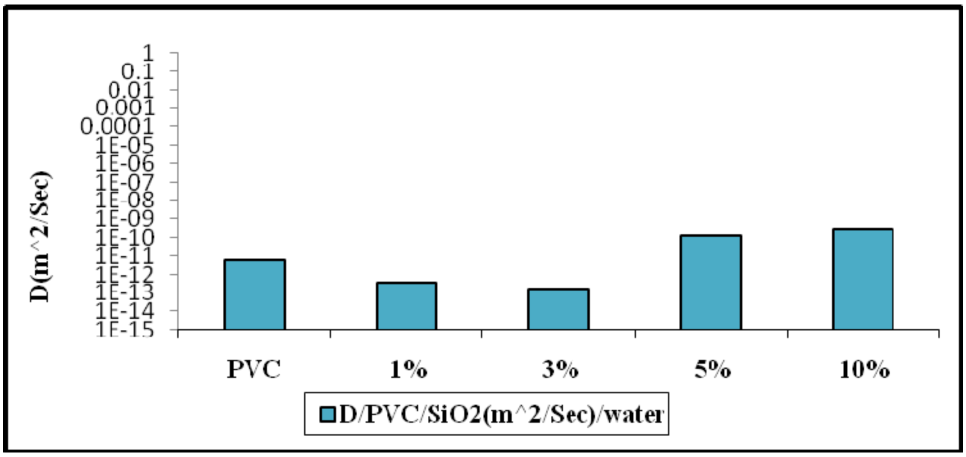


Fig.9: Diffusion coefficient values versus wt. % of SiO_2/PVC composites.

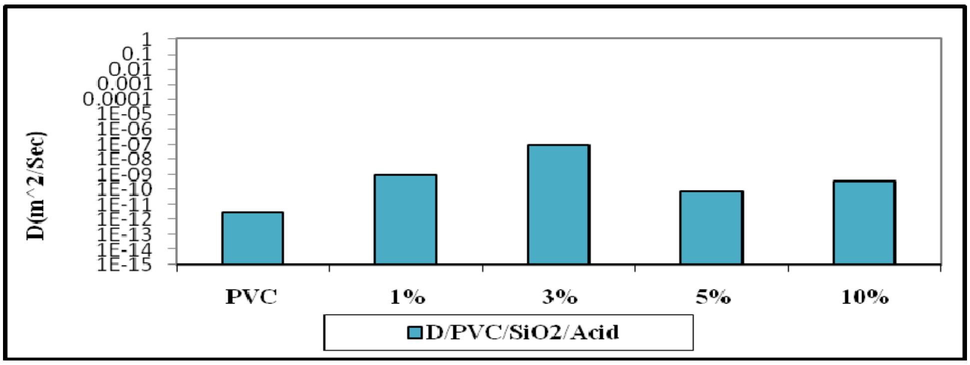


Fig. 10: Diffusion coefficient values versus wt. % of SiO_2/PVC composites.

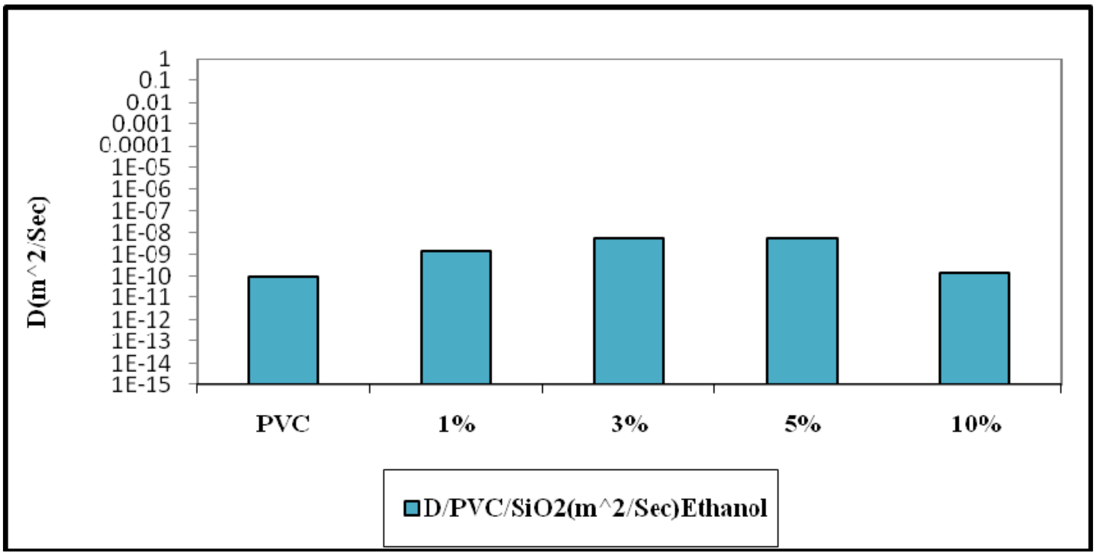


Fig.11: Diffusion coefficient values versus wt. % of SiO_2/PVC composites.

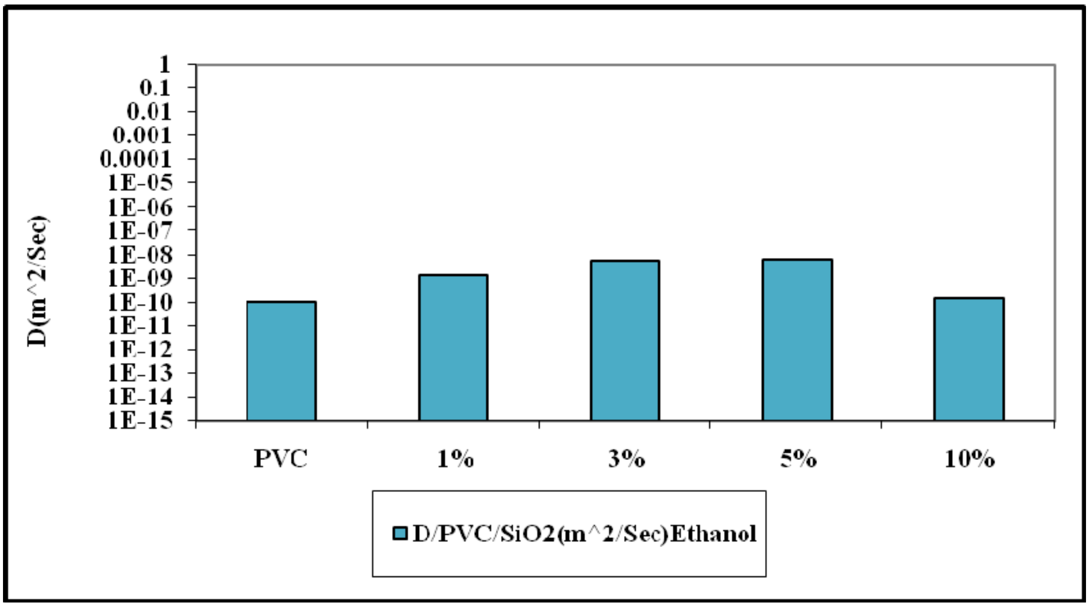


Fig. 12: Diffusion coefficient values versus wt. % of SiO_2/PVC composites.

Table 4: Diffusion coefficients values of PVC and SiO_2/PVC composite samples.

Samples	**Diffusion Coefficient (D) (m^2/Sec)**			
	Distilled water	***Acetic acid***	***Sodium hydroxide***	***Ethanol***
0%	6.50412E-12	2.95566E-12	1.50674E-11	1.02904E-10
1%	3.65154E-13	9.23206E-10	4.56278E-10	1.41831E-09
3%	1.73111E-13	9.38422E-08	1.24619E-10	5.83489E-09
5%	1.36362E-10	6.95162E-11	2.1972E-08	6.26577E-09
10%	3.01233E-10	3.7543E-10	1.39701E-13	1.53161E-10

4. Predictable dielectric behavior of PVC composites

4.1The dielectric constant

Fig. 13 shows the dielectric constant of PVC, SiO_2/PVC composites at selected concentrations. It was found that, the dielectric constant values decreased with increasing frequency for all the compositions. There was increasing in dielectric constant at 1% SiO_2/PVC then decreasing, but all till more its value for purified PVC. The dielectric constant of PVC was equal to (2.104), which is in a good agreement with [25]. The results found that, there is an increasing in dielectric constant at 1% of SiO_2 loadings, which was attributed to the polar groups that are introduced by loading. The polar groups give rise to dipole or orientations polarize ability. The overall polarize ability of composites was some of electronic, atomic and orientation polarization giving rise to higher dielectric constants which increased by loading [26].

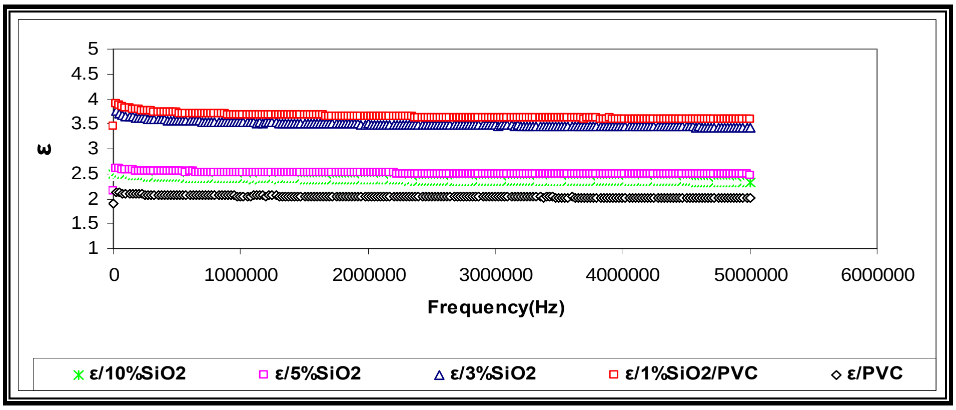


Fig. 13: Frequency dependent dielectric constant of PVC &SiO_2/PVC composites.

4.2 Dissipation factor

Figure 14 shows the dissipation factor as function of the frequency at different concentrations of SiO_2. The results proved increased in dissipation factor with loading up to 1%SiO_2 and then decreased for SiO_2/PVC. The improvement in dielectric characteristics of PVC with SiO_2, due to increase in loading for the previous ratio due to various functional groups which are available by loading, and plasticized compositions reveal appropriate increasing of dielectric loss tangent[25].

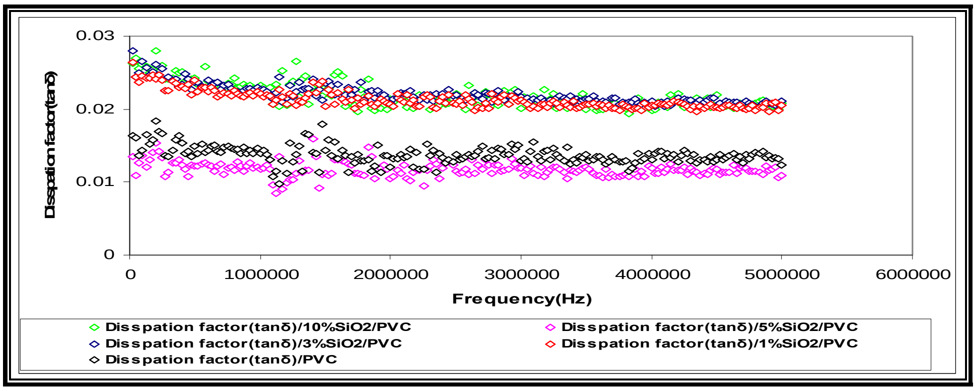


Fig. 14: Frequency dependent dissipation factor of PVC & SiO_2/PVC composites.

4.3 The volume resistivity& volume resistance

The variation of volume resistance and resistivity of PVC, and SiO_2/PVC at different concentrations are shown in Figs. 15 and 16 respectively, it was found that there is a decreasing in volume resistance at SiO_2 loading. It was found that the volume resistance and resistivity decreasing with frequency, another interesting observation is that the volume resistance decreases with SiO_2 loading up to (5%). This was attributed to the presence of polar groups which facilitate the flow of current. The increase in interfacial adhesion leads to an increase in the resistivity respectively. For SiO_2/PVC, it was seen at lower concentrations the resistivity decreases slightly while at higher ones it increases sharply. 10%SiO_2 where composition becomes more insulating, decreasing of volume resistance and resistivity with frequency can be observed [27].

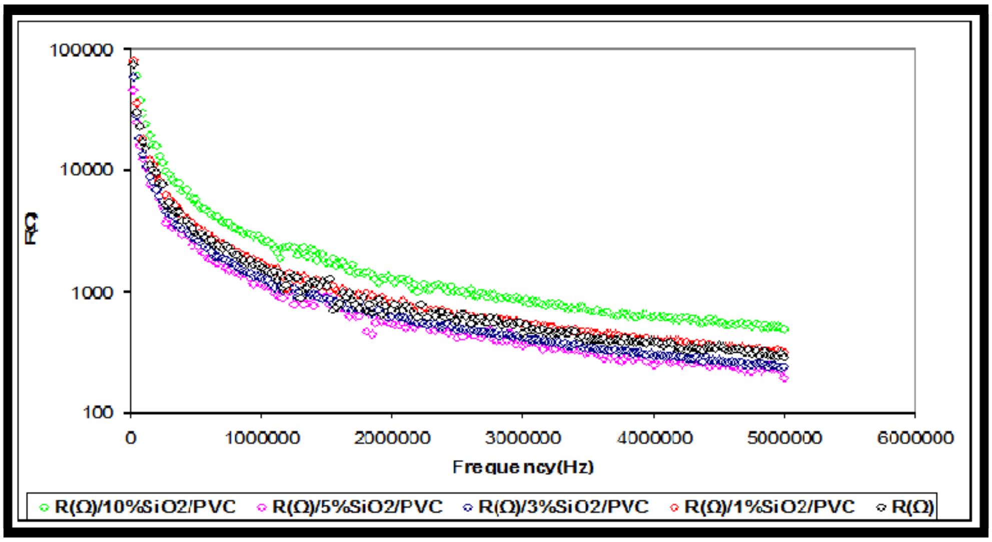


Fig. 15: Frequency dependent volume resistance of SiO_2/PVC composites.

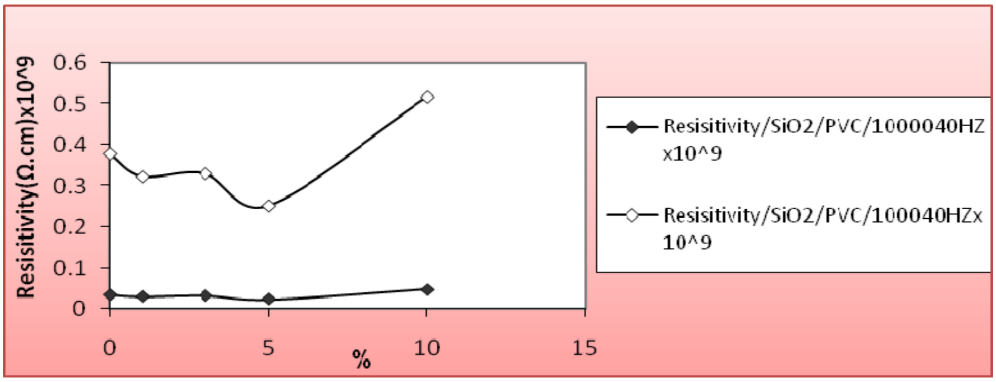


Fig.16: Frequency dependent resistivity of SiO_2/PVC composites.

Table 5: Dielectric properties of PVC composite films.

Samples	**Main Dielectric Properties of PVC Composites at (100040 Hz)**			
	SiO_2/PVC			
	ε	**tan (δ)**	**R (Ω)**	**Resistivityx10^9 (Ω. cm)**
0%	2.1039	0.0144	17259.99	0.3794
1%	3.82	0.0246	18239.77	0.3233
3%	3.658	0.0265	13254.82	0.33111
5%	2.572	0.0137	12350.05	0.25198
10%	2.493	0.0261	29185.75	0.5179

5. FTIR analysis

The FTIR spectra of pure PVC, SiO_2/PVC composites are shown in Fig. 17. The FTIR spectrum reveals molecular interaction between PVC and SiO_2, (C-Cl) stretching (600-840 cm^{-1}) overlaps on the Cis (C-H) stretching bands at (607.67 cm^{-1}), Trans (C-H) wagging and (C-C) stretching at (962.38 cm^{-1}), (-CH_2) deformation at (1333.54 cm^{-1}), (-CH_2) scissor stretching overlaps with C-H deformation bands at 1425.87 cm^{-1}, -CH_2 symmetric stretching at 2854.17cm^{-1}, and -CH_2 asymmetric stretching at (2923.96 cm^{-1}). By adding SiO_2, the bands show slight shift and disappeared in some bands within range of (1099.50 cm^{-1}), it was suggested the coordination or complication has occurred between the polymer and filler. In summery these observations establish the complication of SiO_2/PVC composites [7, 28]. The presence of silica in (SiO_2/PVC) composites (membranes) was confirmed with existence of (Si-O-Si) symmetric stretching at (1099-1100 cm^{-1}), seemed to overlap with wide vibration absorption of (C-O) stretching in the same range [10]. It was found that, appearance and disappearance in some bands within range of (600-840cm^{-1}), and (1091-1100cm^{-1}) that was attributed to the (C-Cl) stretching, (Si-O-Si), and (C-O) stretching[8,16]. There are symmetric increasing in absorbance intensity spectra with SiO_2 ratios attributed to good distribution of inorganic fillers (Symmetric increases), and the increasing in absorbance intensity was due to the increasing of localized states in energy gabs by increasing of SiO_2 ratios [22]. FTIR characteristics of PVC and its composites were explained in Table 6.

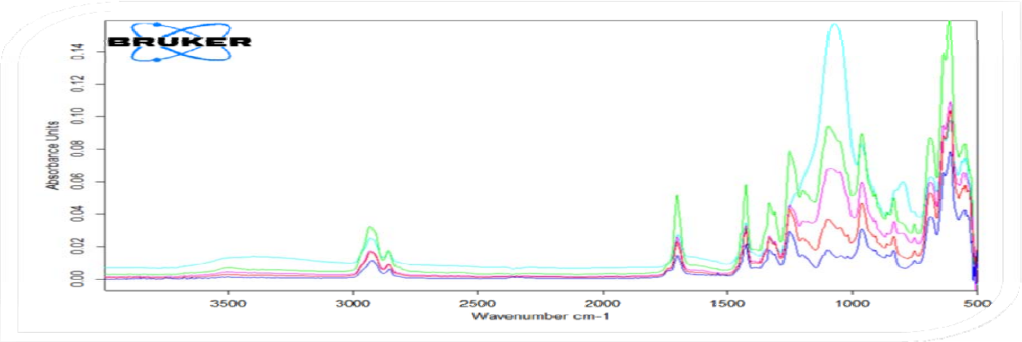


Fig. 17: FTIR spectra of pure PVC and its composites.

Table 6: FTIR characteristics of PVC & PVC micro-composites.

Polymer Systems	(C-Cl) Stretching & C is (C-H) Stretching (600-840 cm^{-1})	(Si-O-Si)&(C-O) Stretching	Trans(C-H) Wagging & (C-C) Stretching	(-CH$_2$) Deformation	(-CH$_2$) Scissor Stretching & (C-H) Deformation	(-CH$_2$) Symmetric Stretching	(-CH$_2$) Asymmetric Stretching
PVC	607.67 634.89 688.32 749.14 833.77	1099.50	962.38	1333.54	1425.87	2854.17	2923.96
1%SiO$_2$/PVC	607.54 688.78 749.35 833.47	1098.68	962.40	1388.85	1425.99	2856.37	2927.7
3%SiO$_2$/PVC	606.39 635.03 688.04 749.84 805.46 832.92	1091.79	962.37	1333.9	1426.08	2857.69	2931.57
5%SiO$_2$/PVC	608.52 634.81 689.3 750.06 832.91	1095.98	962.6	1333.76	1426.04	2858.62	2932.21
10%SiO$_2$/PVC	607.32 635.04 683.41 750.77 798.90	--------	963.32	1333.89	1426.24	2857.63	2930.86

6. Effect of SiO$_2$ ratios on PVC microstructure

To investigate the effect of SiO$_2$ on the morphology of PVC, different samples containing different concentrations of above fillers were evaluated, from Fig. 18, it was seen that the samples with (3% SiO$_2$/PVC) are glossy and smooth without agglomeration of (SiO$_2$) particles in (PVC) matrix. In contrast for the samples with more than 3%, it was found a number of agglomerated (SiO$_2$) particles which are clearly observed in a (PVC) matrix. PVC filled with (3% SiO$_2$/PVC) has less agglomerate since it has the best dispersion of SiO$_2$ into polymer matrix and it could be said that the interfacial adhesion between two phases is improved [29, 30].

Conclusions

The following conclusions can be drawn from this study:

- Mechanical characterization proved that, the tensile strength was found to increase along with filler content of up to 3% SiO$_2$/PVC composites, SiO$_2$ micro-particles were found to be more effective in promoting the mechanical properties of PVC. This implies the using of these composites for numerous applications such as: binder constituents in explosives, load bearing components, jet engine modulus and plastic packaging applications.
- From thermal conductivity test, it can be concluded that 5, and10% of SiO$_2$/PVC composites recorded the lowest thermal conductivity values compared to other

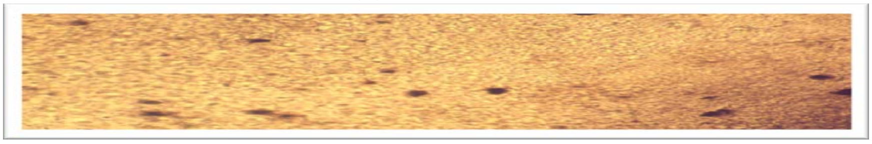
ratios. This feature is in a good agreement with general specifications of packaging materials as worm or cold food packages.

- From the absorpitivity test results, it can be concluded that PVC, SiO_2/ PVC at concentrations involved can be used as containers for distilled water, acids, Ethanol and sodium hydroxide unless 3% SiO_2/ PVC (for acetic acid), 5% SiO_2/ PVC (for NaOH), and 3% SiO_2/ PVC, (for Ethanol).
- Dielectric analysis determined that the addition of ceramic fillers into polymer matrix resulted in improvement of dielectric constant, loss factor, resistance, and volume resistivity; giving rise for using them for numerous insulating applications such as: cable insulation, clear blisters, handles for variety of tools, coatings for wires, or as casting for electrical equipment. Since they possess a high volume resistance value of order 109Ω.cm.
- The FTIR spectra of pure PVC, SiO_2/PVC composites were suggested the coordination or complication has occurred between the polymer and filler. There are symmetric increases in absorbance intensity spectra with SiO_2 ratios attributed to good distribution of inorganic fillers (Symmetric increases), and the increase in absorbance intensity was due to increase in localized states in energy gabs by increasing of SiO_2.
- Morphological characterization indicated that, the samples with (3% SiO_2/PVC) are glossy and smooth without agglomeration of (SiO_2) particles in (PVC) matrix.

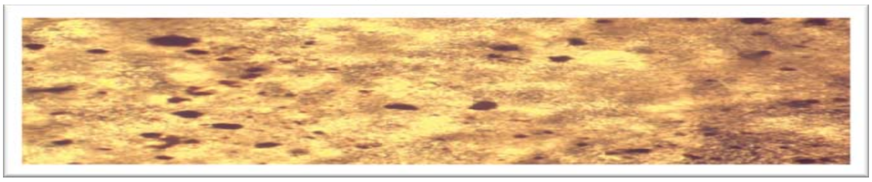
(A)PVC

(B)1%SiO_2/PVC

(C)3%SiO_2/PVC



(D)5%SiO_2/PVC



(E)10%SiO_2/PVC

Fig. 18: Optical microscopy micrographs of pure PVC and PVC composite films at X100.

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