Study of weathering effect on the thermal conductivity of polyvinyl chloride before and after silicon carbide addition as packaging materials

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Abstract

The work was carried out in two stages. The first stage concerned with study of silicon carbide (SiC) ratio (1.5, 2.5, 3.5, and 4.5 wt%) effect on the Thermal conductivity of polyvinyl chloride (PVC); and the second stage concerned with the UV – weatherizing (25, 50, and 75 hr), thermal aging (40, 50, and 60 ˚C), and rain- weatherizing (1, 2.5, and 4 hr) effect on the samples involved. Thermal conductivity results proved that there was slight increase in thermal conductivity by (SiC) loading; it increased from 0.17 W/m.K for PVC to 0.19 W/m.K for 4.5% SiC/PVC; where as it was systematically decreased by UV- weatherizing, thermal aging, and rain- weatherizing. This property is in a good agreement with general characteristics of packaging materials as warm or cold food packaging.

Key words

Thermal conductivity, PVC, SiC, Plastic packaging, UV-weatherizing, Thermal aging, Rain-weatherizing.

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دراسة تأثير التجوية على التوصيلية الحرارية لبولي فينيل كلورايد قبل وبعد أضافة كاربيد السليكون كمواد تعبئة

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الخلاصة

أنجز العمل على مرحلتين: تتعلق المرحلة الأولى بدراسة تأثير نسبة (1.5, 2.5, 3.5, 4.5 wt %) كاربيد السليكون (SiC) على التوصيلية الحرارية للبولي فينيل كلورايد (PVC)؛ والمرحلة الثانية تتعلق بدراسة تأثير التجوية بالأشعة فوق البنفسجية للفترات (25,50, 75 hr)، التقادم الحراري (40, 50, 60 ˚C)، والتعرض للمطر للفترات (1 2.5, 4hr) على نماذج البحث. أثبتت نتائج التوصيلية الحرارية وجود زيادة طفيفة في التوصيلية الحرارية لل(PVC) بأضافة (SiC) من (0.17W/m.K) بالنسبة لل(PVC) الى (0.19 W/m.K) بالنسبة لل (4.5%SiC/PVC)؛ في حين لوحظ تناقص نظامي للتوصيلية الحرارية عند تعريض نماذج مدار البحث للأشعة فوق البنفسجية، التقادم الحراري، والتعرض للمطر. وأن هذه الخاصية تتفق بشكل جيد مع المواصفات العامة لمواد التعبئة الخاصة بعبوات الطعام الدافئة والباردة.

Introduction

Thermal conductivity of polymers is of considerable importance property for both polymers applications and processing, typically, polymers have an intrinsic thermal conductivity much lower than those for metals and ceramics and therefore it can be an advantage in thermal insulation applications such as solid or foam insulating panels or a disadvantage in structural applications where electrically or mechanically generated heat which must be distributed to avoid damage to the functioning parts [1,2]. Thermal conductivity is the rate at which a material conducts thermal energy through itself. It is the quantity of heat that passes through a unit of the material in a unit of time when the temperature variation of two faces is 1 K [3]. Many researchers have studied the thermal conductivity of PVC composites: Z. M. Ali. Study the effect of SiC Addition on thermal conductivity of PVC, thermal conductivity measurement values illustrated that composite materials involved have a good thermal insulation at 10 wt. %[4]. M. Kok et al. measured the thermal conductivity of PolyVinyl Chloride (PVC): Polyisobornyl acrylate (PIBA) blend, the comparisons of thermal conductivity values showed that the thermal conductivity of PVC:PIBA blend was higher than PVC [5]. Onyeaju investigates the thermal properties of polyvinyl chloride and asbestos ceiling sheet, the result showed low thermal conductivity and high thermal resistivity which compared favorably with those of other good thermal insulators [6].

Many factors may significantly affect thermal conductivity of polymers, these influencing factors comprise : density of polymers, chemical constituents, strength of bonding, orientation of chain segment, crystal structure, degree of crystalinity, structure type, molecular weight of side groups, molecular density distribution, type and strength of defects or structural faults, processing conditions, temperature and pressure [1,7]. Due to thermal energy transports more efficiently along the polymer chain; the thermal conductivity of polymers is highly dependent on polymer chain orientation. Crystalline polymers have higher thermal conductivity than amorphous polymers; this is because of crystalline polymers having highly ordered chain segments. Amorphous polymers may exhibit anisotropic thermal transport properties if polymer chains are partially oriented, with thermal conductivity along the chains higher than that perpendicular to the chains. The type and amount of fillers used, size, shape, thermal properties of the filler, and orientation of filler particles in polymer matrix, these factors are important to determine thermal conductivity of filled polymers [2].Thermal conduction mechanism in polymers is based on agitation or molecular movement across intramolecular or intermolecular bonds. In this context, structural changes that result in a decrease interbond path lengths, or that increase in the effective frequency of contact, increase thermal conductivity. Conversely, factors causing increased disorder or free volume in polymers usually result a reduce in thermal conductivity. The presence of crystallinity in polymers results in improved packaging of molecules and usually increases the conductivity [8]. 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 [9].Silicon carbide based ceramic has a unique combination of properties which opens the ways for a wide range of industrial applications [10]. These properties include: high strength, modulus and creep resistance, retention of properties at high temperatures of about 1600 ^{o}C, high thermal shock resistance and chemical stability, etc [11]. Incorporation of functional particles as silicon carbide particles into a polymer matrix introduced an interesting advantages, like: cost-effective process ability, enhanced stiffness and strength, and high flexibility, which rendering many applications [12].

Experimental part

1. Materials

The following material was utilized for preparation of polymer systems: a white powder of Polyvinyl chloride (PVC) was used as a polymeric matrix; this powder was made in Korea (Hyundai Company). Silicon carbide micro-powders were utilized as ceramic addition with particle size diameter (0.65) µm. Cyclohexanone was utilized as a chemical solvent for dissolving PVC. Ethanol solvent, (HCl), (NaOH) solutions, and distilled water were utilized as penetrating mediums for PVC and its SiC/PVC at different concentration.

2. Sample preparation

The desired weight of purified polymer (PVC) was dissolved in cyclohexanone. The handy shaken was continued until got homogeneous solution. The solution was put into clean glass petri dishes; it was put on flat plate form and left to dry at room temperature. The dried films were extracted from the glass dishes by utilizing tongs clamp. It was found that the best concentration for manufacturing films was 7% wt/vol.

By using casting method for SiC/PVC, the films were prepared at different concentrations of (1.5, 2.5, 3.5, and 4.5wt. %) using cyclohexanone as solvent. Polyvinyl chloride and Silicone carbide particle were strictly weighed amount of (6.895, 6.825, 6.755, and 6.685 g) and (0.105, 0.175, 0.245, and 0.315 g) respectively. It was dissolved separately in the solvent and handly shaked until the solution seemed to be homogeneous. The solution was then cast into clean glass slide and petri dishes, the solvent left to dry at room temperature. These films were separated from the glass slide and petri. All obtained films were regular in thickness (as shown in Table 1), semi-transparent, and free from air bubbles.

Table 1: Weight ratios (%) and thicknesses of samples.

Polymer Systems	Weight Ratio (%)	Thickness (mm)
PVC	0%	0.18
SiC /PVC	1.5%	0.19
SiC /PVC	2.5%	0.20
SiC /PVC	3.5%	0.20
SiC /PVC	4.5%	0.21

3. Accelerated weathering condition

The prepared film was exposed to the weatherizing conditions such as (ultraviolet radiation (UV), rain, and heat), at different conditions, using (Accelerated weathering tester – QUV/spray- Q-LAB). Firstly the films were exposed to (UV radiation and rain) by placed them inside an accelerated weathering system, to a different exposure times (25, 50, and 75hr) and (1, 2.5, and 4hr) respectively. The films exposed to heat by using an oven to different temperature (40, 50, and 60 ºC) for four hours.

4. Thermal conductivity test

Thermal properties are between the most important that was attributed to the material must be identified for any polymer application. Particularly in packaging design the materials can be exposed to different thermal treatments either alone or with the product. Lee`s disc device, made by the (Griffen and George Company), was utilized to test the thermal conductivity of the samples under test. This device is composed of three discs of brass (40 mm diameter by 12.25 mm thickness) and a heater. The sample was put between the discs A and B, while the heater was put between B and C. Heater was supplied with voltage (6 volt) and the current value through the device was about (0.25 A). The heat moves from the heater to the near two discs then to the third disc across the sample. A thermometer was utilized to measure the temperature of these three discs (TA, TB, and TC). After thermal equilibrium was archived, the heat was registered.

Thermal conductivity is measured by using the equation below:

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

where: K is thermal conductivity coefficient (W/m.K), T_A, T_B, and T_C: are the temperatures of the disk (K) respectively. d_A, d_B, and d_C: are the thicknesses of the disks (mm) respectively. $d_{S:}$ is the thickness of sample (mm).

r: is the disk's radius (mm).

e: is the quantity of heat flowing through the cross sectional area of the specimen per unit time (W/m^2. K), which is calculated from the following equation:

$$H=I.V=\pi r^2.e.(T_A+T_B)+2\pi r.e.\left(T_A.T_A+\frac{d_s}{2}(T_A+T_B)+d_{B.}T_B+d_C.T_C\right)$$

where: I is the current through the heater A. V is the applied voltage (V).

Results and discussion

1. Thermal conductivity test

The thermal conductivity is important to any potential application on the environmental and thermal stability of the material should be identified to determine the optimal condition for the performance of device. The thermal conductivity of material is the thermal property, which is required to decrease the heat transfer through the materials [4].

i. UV-weatherizing effect on the physical properties

Fig. 1 shows (SiC) effect on the thermal conductivity of (PVC) at different concentration, before and after UV – weatherizing at different time (25, 50, and 75 hr). The experimentally observed value of thermal conductivity of PVC is 0.17 W/m.K at room. This value was in a good agreement with [4]. It was found that the thermal conductivity increase with (SiC) loading up to (4.5 wt %). In amorphous polymers such as (PVC), the thermal conductivity in low temperature (in the vicinity of room temperature) depends on the variation of phonon mean free path. For (PVC) the phonon mean free path is extremely small attributed to existence of several of defect in amorphous situation at room temperature.

Certain defects like bend in chains gab between two chains, chains of smaller length than the others, and crack in the system during polymerization of polymer [9]. So pure (PVC) is of low thermal conductivity, the increase in thermal conductivity was attributed to good dispersion of (SiC) loading [13].

By increasing (SiC) loading, the mobility possibility increased, so the main free path decrease rapidly, which caused to rapid increase in thermal conductivity [5,14]. By UV – weatherizing for (25, 50, and 75 hr), it was found that the thermal conductivity decreased. Its decrease was attributed to air voids created by photo-degradation induced by photo-degradation. As a result of photo-degradation the molecular weight of polymer chain decreased, that increases the free path to transfer phonon, and reduces the interaction between molecules. The mobility of polymer (chain fragments) very much depends on the physical state of the polymer, the molecules are almost frozen in their position is strongly limited, therefore free species found by radiation remain trapped of their mobility is hindered in the medium [15].

It was seen that the thermal conductivity decreased also with exposure time, which was attributed to the increase of voids, and cracks with exposure time.

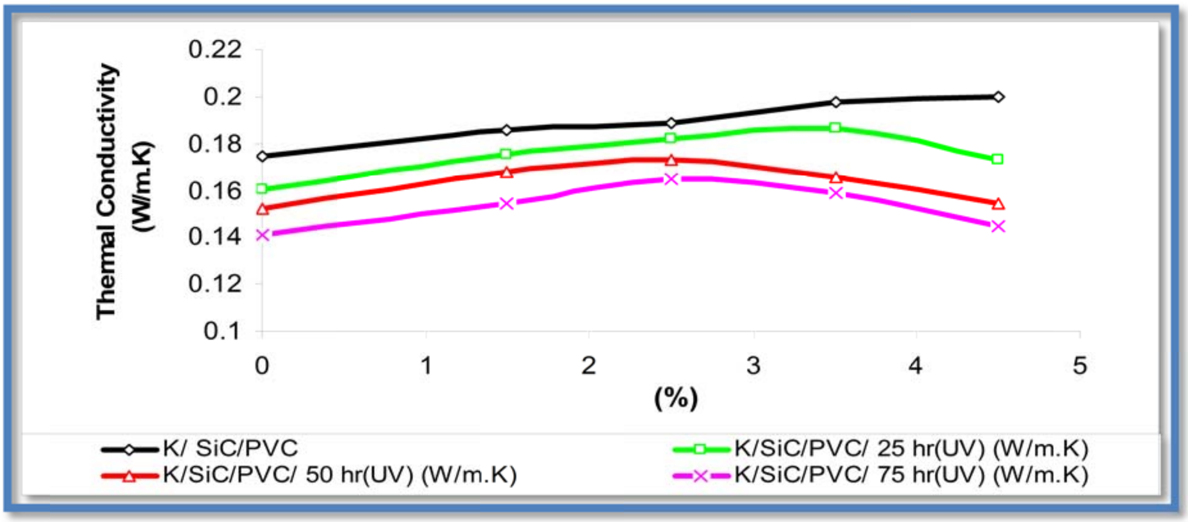

Fig. 1: Thermal conductivity for (PVC), before and after (SiC) addition and UV - weathering for (25. 50, and 75 hr).

ii. Thermal aging effect on the physical properties

Fig. 2 proves that the thermal conductivity decreased with thermal aging within range of (40, 50, and 60˚C), for PVC, and SiC/PVC at different concentration. The smaller value of thermal conductivity is attributed to fact that the temperature transport in solids is very sensitive to internal structure and film defects, which restrict heat transport by phonon. The hindrance in transport of phonons leads to a less value of thermal conductivity. Second observation is that the thermal conductivities of samples involved of (SiC/PVC) at different concentration were higher than their counterparts without (SiC) dispersed respective samples.

As it was known in non-metallic material system like polymer, the heat energy is principally carried by phonons, which have a wide difference in frequency and the mean free paths. The thermal carrying phonons after have order of nanometer range at room temperature. In this way the dimension of (SiC) particles involved (0.65 μm) becomes comparable approximately to the mean free paths, which would lead to large improvement in phonon transport within the sample involved. The phonon confinement and quantization of phonon transport results modification in thermal properties. The (SiC) particles are semiconducting in nature with their intrinsic thermal conductivity of (SiC =120 W/m.K). Therefore, these dispersed (SiC) promptly sub-serve phonon – phonon conduction in the respective polymer network. This comes the enhancement of thermal conduction in (SiC) loading[16].

So the thermal conductivity of (SiC/PVC) at different concentration before and after UV – weatherizing was all more than pure (PVC). The results proved that the thermal conductivity decreased with aging temperature.

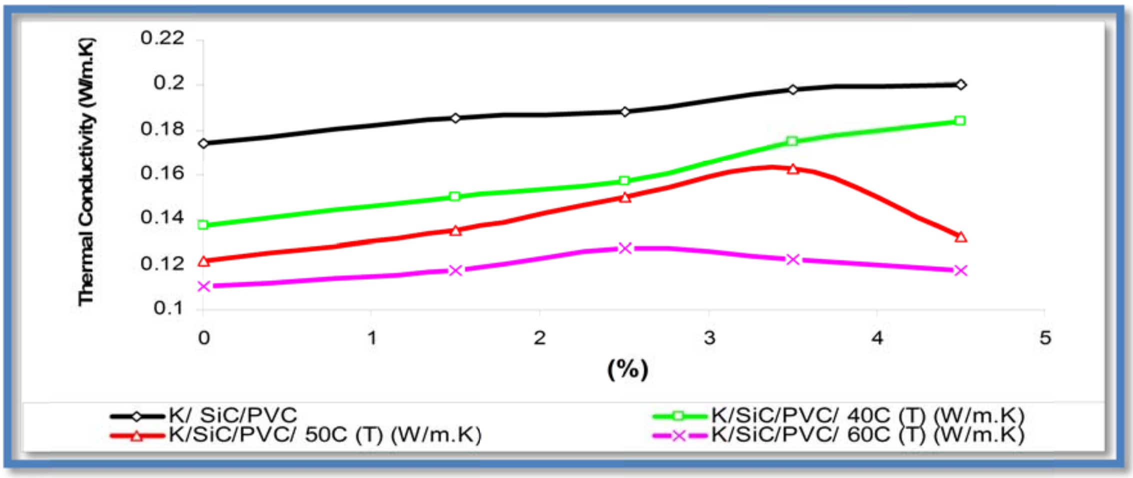

Fig. 2: Thermal conductivity for (PVC), before and after (SiC) addition and thermal aging for (40. 50, and 60˚C).

iii. Rain -weatherizing effect on the physical properties

Fig. 3 shows the rain weatherizing effect on the (PVC) and (SiC/PVC) for period time (1, 2.5, and 4 hr). It was seen, that the thermal conductivities decreased with exposure time. It was due to the water diffusion in the involved samples created some voids, bubbles and result in decrease in thermal conductivity. This result was attributed to the decrease in adhesion between the components in polymer systems. Rain– weatherizing for samples involved produces an increase in heat resistance of the component bound arises and decrease in the coefficient of heat transfer of material[17]. This result was in a good agreement with [5]. The thermal conductivity of the samples involved before and after (SiC) addition, and (UV-weatherizing, thermal aging, rain-weatherizing) is shown in the Tables 2-4.

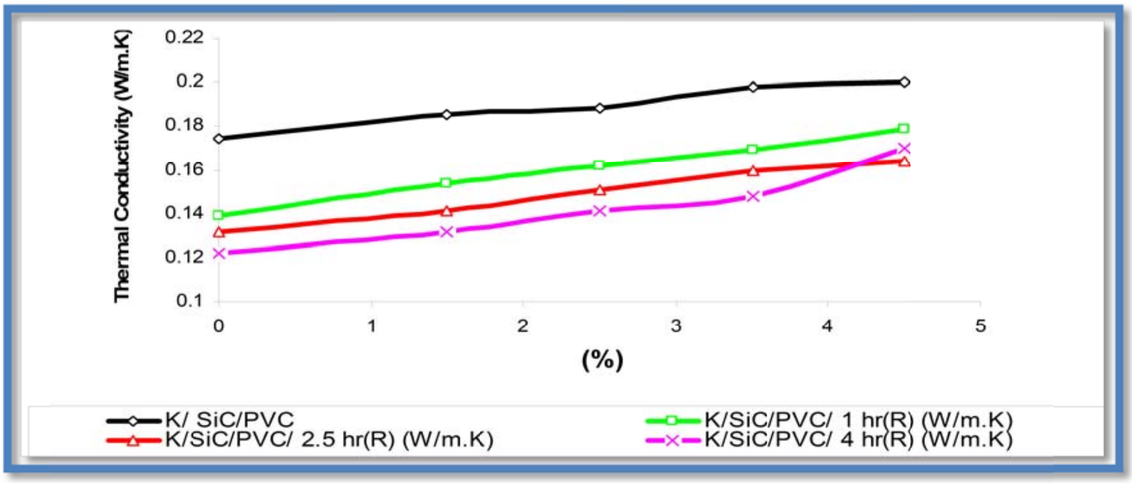

Fig. 3: Thermal conductivity for (PVC), before and after (SiC) addition and Rain - weathering for (1, 2.5, and 4 hr).

Table 2: Thermal conductivity of SiC/PVC before and after UV-weatherizing for different times.

Samples SiC/PVC	Thermal conductivity of SiC/PVC before and after UV-weatherizing (W/m.K)			
	0hr	**25hr**	**50hr**	**75hr**
PVC	0.174	0.160	0.152	0.141
1.5%SiC/PVC	0.185	0.175	0.167	0.154
2.5% SiC/PVC	0.188	0.181	0.173	0.164
3.5% SiC/PVC	0.197	0.186	0.165	0.159
4.5% SiC/PVC	0.199	0.173	0.154	0.144

Table 3: Thermal conductivity of SiC/PVC system before and after thermal aging for different temperatures.

Samples SiC/PVC	Thermal conductivity of SiC/PVC before and after Thermal aging (W/m.K)			
	20 ˚C	**40 ˚C**	**50 ˚C**	**60 ˚C**
PVC	0.174	0.137	0.122	0.110
1.5%SiC/PVC	0.185	0.150	0.135	0.117
2.5% SiC/PVC	0.188	0.157	0.150	0.127
3.5% SiC/PVC	0.197	0.175	0.162	0.122
4.5% SiC/PVC	0.199	0.184	0.132	0.117

Table 4: Thermal conductivity of SiC/PVC system before and after rain-weatherizing for different times.

Samples SiC/PVC	Thermal conductivity of SiC/PVC before and after Rain-weatherizing(W/m.K)			
	0hr	**1hr**	**2.5hr**	**4hr**
PVC	0.174	0.139	0.131	0.122
1.5%SiC/PVC	0.185	0.153	0.141	0.131
2.5% SiC/PVC	0.188	0.161	0.150	0.141
3.5% SiC/PVC	0.197	0.169	0.159	0.147
4.5% SiC/PVC	0.199	0.178	0.163	0.169

Conclusions

There was slight increase in thermal conductivity with SiC loading; whereas systematic decrease by UV-weatherizing, thermal aging, and rain-weatherizing. This feature is a good agreement with general specification of packaging material as a worn or cold food packages.

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