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Research Paper / Makale

Exploring of Polyvinylchloride / Silicon Carbide Nanocomposites Containing Different Amounts of SiC Nanoparticles

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Abstract: Polyvinyl chloride (PVC) is one of the popular materials that extensively used in different areas, so scientists are trying to investigate its characteristics in different formats, such as blends and composites, to improve its properties. Due to the distinctive nano particles' properties, polymer-based nanocomposites can offer new characteristics to pure polymers and can widen their applications in different areas. In this study, we added different compositions of silicon carbide (SiC) to PVC to investigate its molecular, thermal, and microstructural properties. Attenuated total reflection- infrared (ATR-IR), thermogravimetry (TG), differential scanning calorimetry (DSC), and optical microscopy (OM) were utilized to study molecular bond structure, thermal degradation, caloric properties, and surface morphology of the pure PVC and its composites. The first derivative of TG results showed that the temperature of the maximum thermal degradation of the PVC increased with increasing SiC nanoparticle ratio. Also, it is found that the PVC/12 mol% SiC started thermal degradation at comparably low temperature, however, the amount of residue of the composites is more than the pure PVC. Additionally, SiC nanoparticles caused the melting temperature of the composites to slightly shifts to a lower temperature compared to the PVC. It was observed that silicon carbide diminished the smoothness of the surface by increasing its fraction in the composite.

Keywords: PVC, silicon carbide, composite, thermal, optic microscope

Farklı Miktarlarda SiC Nanopartiküllerini İçeren Polivinilklorür / Silisyum Karbür Nanokompozitlerinin Keşfi

Öz: Polivinil klorür (PVC), farklı alanlarda yaygın olarak kullanılan popüler malzemelerden biridir, bu nedenle bilim adamları, özelliklerini iyileştirmek için karışımlar ve kompozitler gibi farklı formatlarda özelliklerini araştırmaya çalışıyorlar. Ayırt edici nano parçacıkların özellikleri nedeniyle, polimer bazlı nanokompozitler, saf polimerlere yeni özellikler sunabilir ve farklı alanlardaki uygulamalarını genişletebilir. Bu çalışmada, moleküler, termal ve mikroyapısal özelliklerini araştırmak için PVC'ye farklı oranlarda silisyum karbür (SiC) nanoparçacıklarını ekledik. Saf PVC ve kompozitlerinin moleküler bağ yapısını, termal bozunmasını, kalorik özelliklerini ve yüzey morfolojisini incelemek için zayıflatılmış toplam yansıma-kızılötesi (ATR-IR), termogravimetri (TG), diferansiyel taramalı kalorimetri (DSC) ve optik mikroskop (OM) kullanıldı. TG sonuçlarının ilk türevi, PVC' nin maksimum termal bozunması sıcaklığının artan SiC nanopartikül oranı ile arttığını gösterdi. Aynı zamanda, PVC / % 12 mol SiC'nin nispeten düşük sıcaklıkta termal bozunmaya başladığı, ancak kompozit atık miktarının saf PVC' den daha fazla olduğu bulundu. Ek olarak, SiC nanpartikülleri, kompozitlerin erime sıcaklığının PVC' ye kıyasla biraz daha düşük bir sıcaklığa kaymasına neden oldu. Silisyum karbürün kompozit içindeki payını artmasıyla yüzeyin düzgünlüğünün azaldığı görüldü.

Anahtar Kelimeler: PVC, silisyum karbür, kompozit, termal, optik mikroskop

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1. Introduction

Materials have different types such as metals, polymers, and ceramics. To wideness the application, researchers have tried to modify the materials and to achieve different properties such as shape memory alloys [1-18] and composites [19-23]. Composites can be produced with different matrices and additives. Polymers are cheap materials that can be improved with ceramics, metals, and even other kinds of polymers. Scientists try different materials for this purpose to obtain new features for various applications.

Nowadays, plastics and especially polyvinyl chloride (PVC) account for a large of our daily life needs. PVC alone plays a significant role in ~12% of daily applications and it is anticipated to have an increase of 3.2% per year [24], also it is the second most-produced product worldwide. PVC) was chosen as the main polymer as it has a wide range of applications and low cost, chemical stability, biocompatibility [25]. Although a pure PVC promise different applications in various fields, its properties allow it to be used in a finite range of pressure and temperatures, which limited its applications, even this polymer has no magnetic or electric property. Therefore, many efforts have been done to improve the mechanical, thermal [26], electrical [27], and magnetic [28] features of this polymer, such as reinforcement with ceramic, polymers, and metallic materials with different shapes and orientations. For example, Ebnalwaled and Thabet [29] controlled the optical characteristics of PVC by adding various kinds of metal oxides such as ZnO, SiO_2, Al_2O_3 and they found that the refractive index of the composites increased by increasing the composition of ZnO and SiO_2, while Al_2O_3/PVC with low reflectivity and low refractive indices is a good candidate for solar cell applications.

It has been observed that nanoparticle systems have been of great interest compared to conventional composites due to their improved properties. Low-weight nanoparticles have more impact on polymers' properties and in some cases lead to a good combination of properties [29]. Advances in the synthesis of nanomaterials have accelerated their research into their use in the production of nanocomposites [30]. It is found that nanocomposites made from polymers and nanoparticles are reliable in a wide range of displays. Silicon Carbide (SiC) is a carbon-filtered ceramic material [31] and it is known and used as an inorganic material because it has good thermal chemical stability, low thermal expansion, durability, and high hardness [32]. Adding SiC to a polymer can increase its thermal stability and dielectric properties [33]. Nanocomposites prepared with metal nanoparticles and polymers have attracted the attention of researchers for a long time because of their good thermal and electrical properties as well as their optical properties [34-36]. There are insufficient studies about the characterizations of PVC/SiC with different compositions.

The developments in the synthesis of nanocomposite materials have led to the expansion of the production and usage areas of nanocomposites [37]. Nanocomposites have become more interesting because they can easily improve the physical properties of the host material by adding the appropriate nano-sized material. The main issue in nanocomposite production is the appropriate selection of nano-filling material and base material [38]. Such nanocomposite materials have different physical and chemical properties from pure polymers and metal nanoparticles [39]. In particular, studies on polymer nanocomposites have attracted great interest in recent years due to their extraordinary properties [40]. It leads these studies in PVC-based nanocomposite studies [41]. Benjamin et al. could improve the adherence of S. aureus by adding ZnO to PVC-based endotracheal tubes [42]. Hasan and his colleague [38] realized that adding graphene/PVC nanocomposite is more thermos-mechanically stable than a pure PVC or a composite of multi-walled carbon nanotube (MWCNT) and PVC. T. A. Taha [43] investigated PVC/Al_2O_3 composites, and he reported that the Al_2O_3 nanoparticles decreased the optical energy gap of PVC, while the Urbach energy of PVC decreased. There is no or rare study that investigated the effect of SiC on the properties of PVC.

In this study, nanocomposites were obtained by using PVC and SiC nanoparticles in different ratios (2%, 4%, 8%, and 12%). The obtained nanocomposites were first characterized by an ATR-IR spectrophotometer. Then, their thermal properties were examined with Thermal Analysis Calorimetry (TGA) and Differential Scanning Calorimetry (DSC). Finally, optical microscope images were examined to see the surface morphologies of the obtained nanocomposites.

2. Experimental Methods

2.1. Materials

PVC with a molecular weight of 63.000 g/mol was found from PETKIM Turkish company. Silicon carbide particles with a particle size of 280 mesh were purchased from MERCK. HPLC grade tetrahydrofuran (THF) and ethyl alcohol for HPLC (≥99.5%) were obtained from Sigma-Aldrich.

2.2. Preparation of Polyvinyl Chloride / Silicon Carbide Composites

First of all, 0.5 grams of PVC was dissolved in 5 mL of THF. Then, to prepare 2% SiC composite, 0.01 grams of SiC was dispersed in 10 mL THF using an ultrasonic homogenizer for 1 hour. The PVC solution was added to the SiC solution and dispersed for a further 15 minutes. The PVC / SiC composite solution, which became completely homogeneous, was precipitated by adding it dropwise into ethyl alcohol. Using the same procedure, 4%, 8%, and 12% PVC / SiC composite solutions were prepared. The composites obtained were filtered and washed with ethyl alcohol and dried in a vacuum oven for 24 hours at 45 °C.

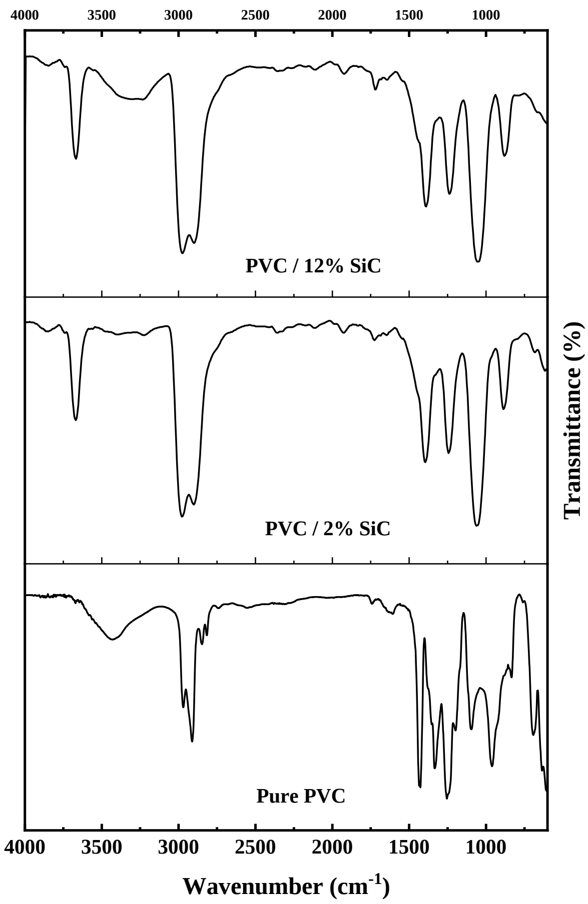


Figure 1. The ATR-IR spectra of the pure PVC and PVC / SiC composites

3. Results and Discussion

In Figure 1, ATR-IR spectra of pure PVC and PVC composites prepared with 2% and 12% SiC are given. Characteristic absorption bands belonging to C-Cl stretching vibration are observed especially in the region between 600 and 700 cm^{-1} in particular at 690 cm^{-1}. Apart from this signal, the characteristic PVC signals are 2970-2895 cm^{-1} (aliphatic $–CH_2$ and -CH stretching), the strong signal at 1428 cm-1 ($-CH_2$ bending), two signals at 1325 and 1250 cm^{-1} (-CH bending of the -CHCl group) and the signal at 965 cm^{-1} ($-CH_2$ rocking) [44]. Also, the signal at 875 cm^{-1} can be attributed to the vibration of the Si-C bond [45, 46].

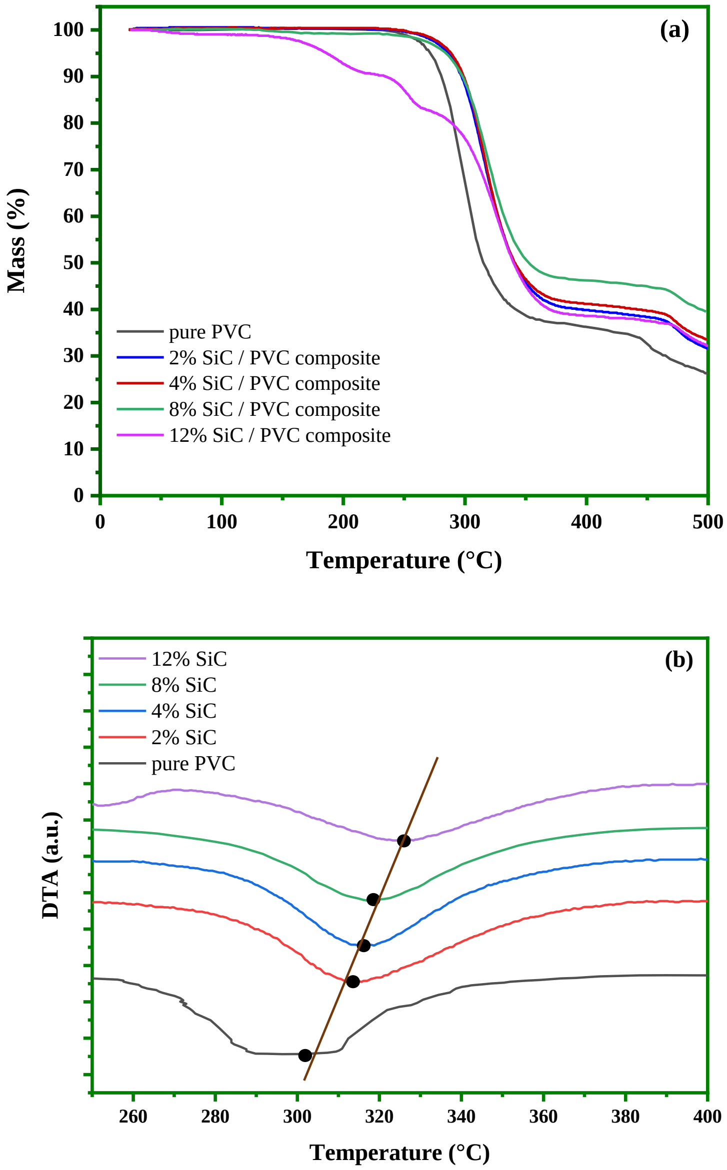


Figure 2. (a) The TGA and (b) DTA curves of the pure and composites

Unlike metals that by increasing temperature gain mass due to oxidation, polymers normally lose mass through the evaporation process. The dynamic heating Thermogravimetric and DTA give worth information about thermal degradation. To obtain the thermal degradation of the pure PVC and its composites, TG analysis was conducted from room temperature to around 500 °C. Figure 2a reveals the step-like degradation of the samples. The TG shows quite different results, whereby the pure PVC and corresponding composites with 2%, 4%, and 8%SiC a two-step, undergoes a two-step degradation. In the first step, PVC experienced dehydrochlorination, and then, in the second step, compounds with low molecular mass are formed [47]. Since SiC is a ceramic material and it has a comparably high melting temperature, so it cannot degrade at such a low temperature, but it could improve the degradations. On the other hand, composites have more residue in the second step of the degradation compared to pure PVC.

Additionally, the first derivative of TG analysis (DTA) is given in Figure 2b. The trough shows the temperature where the maximum degradation occurs. The dots indicate the peaks and they were linearly fitted. As it can be seen, the fitting line shifted to a higher temperature, therefore, it can be realized that the maximum dehydrochlorination temperature increases, and thus the pyrolysis temperature rises by increasing SiC nanoparticle into PVC.

Figure 3 depicts the DSC measurements for the pure PVC and PVC-SiC composites. The measurements were performed with a heating/ cooling rate of 10 °C for the heating process starting from room temperature to ≥150°C. The target was to obtain the glass transition of the specimens. The glass transition temperature of a pure PVC reported in the literature, which is ~87 °C [48, 49]. In the current study, the pure PVC also has almost the same result, while, the glass transition temperature of the PVC composited with a different fraction of SiC has shifted slightly to the lower temperature.

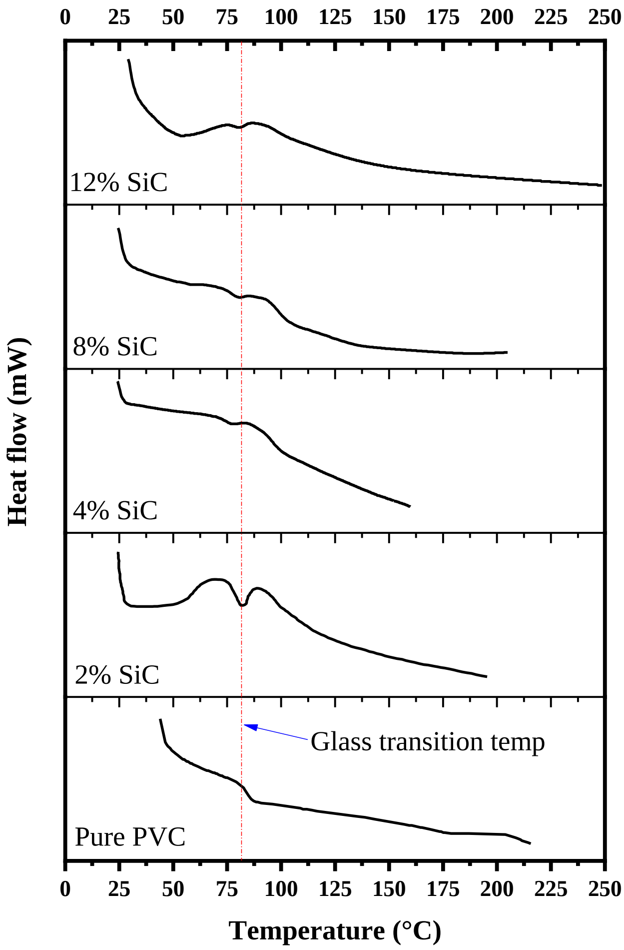
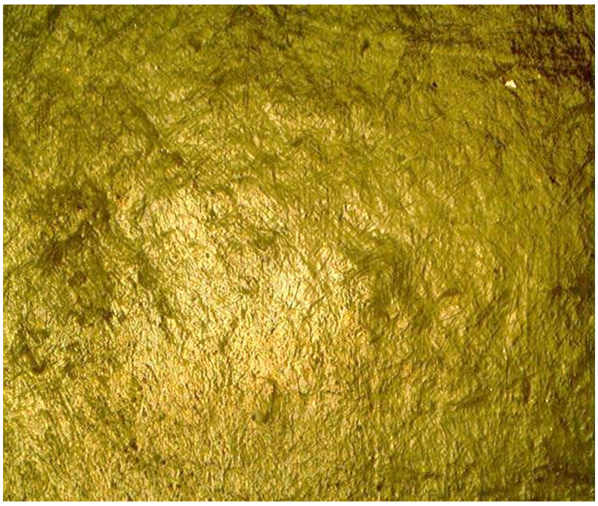
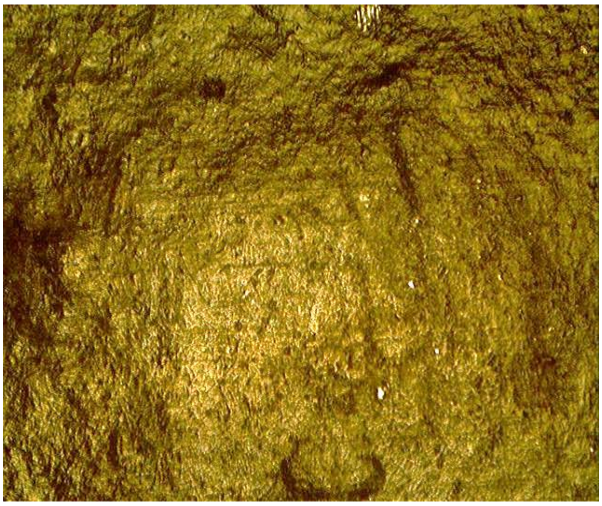


Figure 3. The DSC curves of the samples

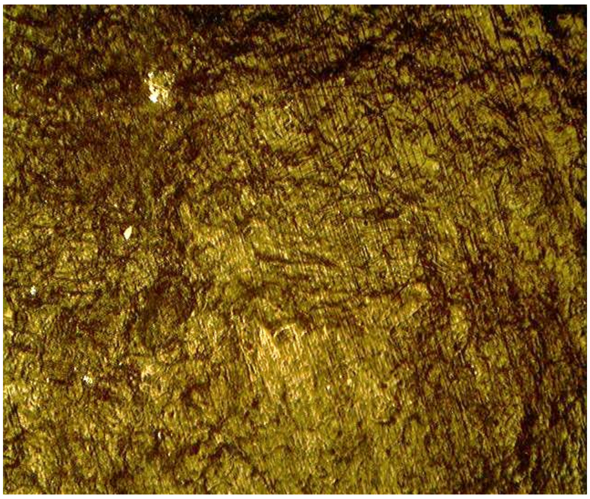
The microstructural analysis was performed by optical microimages given in Figure 4. The samples were not coherent, so they have pelletized using a compressor. It can be seen that the composite loses its smoothness by increasing SiC, and some groves are formed all over the surface that could contain SiC nanoparticles. Since polymer and ceramic materials are two different types of materials, so it is normal that they do not make an interaction, especially SiC in low temperature only has distributed and may precipitate in some particular positions. It is not only in polymer, but also it is reported for the metal and semimetal-based composites contain SiC [50, 51], however, in high temperature, SiC can interact with oxygen and form a more stable SiO_2 layer that can affect the properties of the composite.



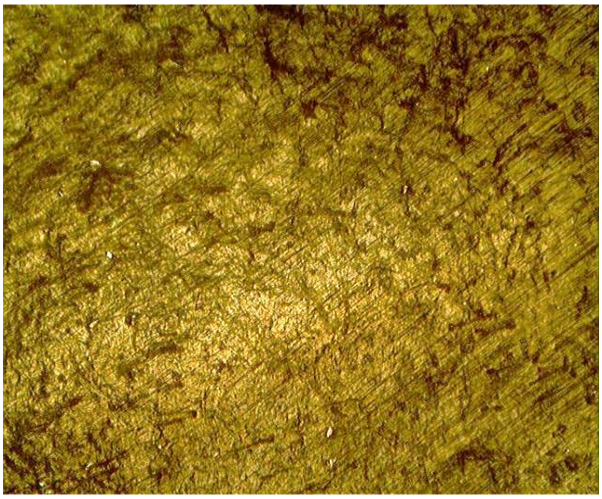
PVC / 2% SiC composite



PVC / 4% SiC composite



PVC / 8% SiC composite



PVC / 12% SiC composite

Figure 4. The optical microscope images of the specimens (Magnification 50x)

4. Conclusions

Since polyvinyl chloride (PVC) is a widely used material in a variety of applications, scientists are attempting to better understand its properties in various formats. We investigated the chemical, thermal, and microstructural properties of PVC by adding various compositions of silicon carbide (SiC) to it. To investigate the molecular bond formation, thermal degradation, caloric properties, and surface morphology of pure PVC and its composites, we used attenuated total reflection infrared (ATR-IR), thermogravimetry (TG), differential scanning calorimetry (DSC), and optical microscopy (OM). The temperature of maximal thermal degradation of the PVC increased as the SiC nanoparticle ratio increased. Furthermore, it was discovered that PVC/12 mol% SiC began thermal degradation at a comparatively low temperature, but the amount of residue in the composites at high temperatures is greater than pure PVC. Furthermore, as compared to PVC, a SiC caused the composites' melting temperature to change marginally lower. Besides, by increasing the proportion of silicon carbide in the composite, the surface smoothness was reduced.

Authors' Contributions

M. E. PEKDEMIR introduced the main idea and supervised the project. M. N. QADIR analyzed the caloric properties. M. AYDOGDU supervised the project. M. COSKUN literature review and introduction. M.E. PEKDEMIR, I. N. QADER, and Y. AYDOGDU, and M. COSKUN wrote the manuscript. All authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

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