RESEARCH ARTICLE

OPTICAL AND DIELECTRIC PROPERTIES OF EPOXY RESIN FILLED WITH TITANIUM DIOXIDE PARTICLES

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Abstract

This work studies the electrical properties for pure epoxy, and epoxy with (0, 1, 1.5, 2 wt%) titanium dioxide powder composites. The effects of titanium dioxide contents on optical and dielectrically properties of the epoxy/titanium dioxide have investigated by several techniques were used to characterize the epoxy/titanium dioxide: UV-visible spectrophotometer reveals a new absorption band in the wavelength range (350-600) nm. The findings of this investigation show that when the proportion of titanium dioxide added increases, the absorbance increases which are ascribed to interchain interaction. The absorption coefficient (α), extinction coefficient (k), refractive index (n), the real and imaginary permittivity (εr, εi), and energy gap (Eg) of epoxy/titanium dioxide samples were effectively determined from the recorded data optical transmission technique. In addition, these epoxy have been examined in the wavenumber range (4000-500 cm⁻¹) using an FT-IR spectrometer and also a dielectric constant measurement. The thickness of all the samples is 1.2 mm ± 0.1 mm.

Keywords: Optical, Dielectric Properties, Epoxy, Titanium dioxide.

Introduction

Epoxy is a polymer made up of two chemicals known as the resin and the hardener. Monomers or short chains make up the resin. Polymers having an epoxide group at the end make form a chain. Epoxy resins are usually made through a reaction between epichlorohydrin and bisphenol [1]. The chemical structures of most epoxy resins are tetracycligyl methylene dianline, bisphenol diglycidyl ether, and phenol formaldehyde [2]. Epoxy resin offers outstanding adhesion, mechanical characteristics, and chemical stability. It also offers benefits such as a low percentage of contraction, low cost, and ease of shape, among others. It is widely employed in dielectric materials, anticorrosion, aerospace, shape, coating materials, and other industrial domains, and has become one of the most important materials for industrial usage [3]. Many research teams from across the globe have concentrated their efforts in the last decade on polymer composites as useful materials for electrical insulation [4], and epoxy is a popular insulating material [5,6] due to its excellent electrical insulating capabilities. Epoxy resins are also chemically compatible with most substrates and tend to wet surfaces easily making them especially well-suited to the composite application [7]. In order to generate composites with improved electrical and mechanical characteristics, titanium dioxide is sometimes added to epoxy. The most significant of these substances such as titanium dioxide, which is an amorphous white powder that is exceedingly stable. It is manufactured and utilized in the workplace in a variety of particle sizes, including fine and ultrafine sizes. As a result, it is widely utilized in a variety of commercial items, including cosmetics, plastics, and paper. As a result, titanium dioxide nanospheres in experimental animals [8] and humans [9] have been deemed physiologically inactive. Studies of the dielectric properties of polymers have increased importance because it provides an understanding to movement of molecular chains and its applications in electrical and electronic engineering. The goal of this research is to see how adding titanium dioxide powder as a filler to raw epoxy (0, 1, 1.5, and 2 wt%) effects on the optical and dielectric characteristics across the wave length range of (200-1100 nm) at room temperature. From the collected data, the absorption coefficient (A), the band gap energy (Eg), the extinction coefficient (k),
and the refractive index (n) were determined. Also described and addressed are the fourier transform infrared spectroscopy (FTIR) spectra of neat epoxy and epoxy composites.

2. Experimental

2.1. Materials

All chemicals used in this work were include the following: Epoxy resin commercial compound ultra clear epoxy cast resin used was a widely used bifunctional epoxy resin, diglycidyl ether of bisphenol and the hardener from (Armor Art China Co.), the TiO₂ powder was used from Loba Chemie, India with a purity of 99.9%.

2.2 Applied Analytical Methods

Absorbance A, transmittance T of the epoxy/TiO₂ samples, over the wavelength range of 200–1000 nm were investigated using UV–Vis Lambda-365 spectrophotometer (Perkin Elmer). The absorption coefficient (α), the band gap energy (E₀), the extinction coefficient (k), the real and imaginary permittivity parts (δᵣ, δᵢ), the refractive index (n) are calculated from the recorded data. FT-IR Spectrometer (Perkin Elmer) in range 4000-500 cm⁻¹ to use for determinate of the functions group in structure. Dielectric constant measurement NV6111 India.

2.3 Preparation of Epoxy/Titanium Dioxide

The epoxy resin and hardener are mixed together in a molar ratio (3:1). Epoxy/TiO₂ were prepared using the magnetic stir 1000 rpm at temperature 75 °C mixing method to disperse TiO₂ fillers in epoxy resin as described in previous work [10] to obtained epoxy/TiO₂ samples with 0, 1, 1.5 and 2 wt % TiO₂ contents, have thicknesses about 1.2 mm.

3. Results and Discussion

3.1. Infrared Spectroscopy (FTIR)

The FTIR spectra of sample generally a characteristic peak of functional groups at specified wavenumber is observed by the method of transmission. This method supplies sufficient data by forming relevant peak to ensure about the functional groups that formed during reaction. The Table 1 shows the IR transmittance spectrum as a function of the wavenumber of the epoxy the results showed agreement of this spectrum with the spectrum of pure epoxy recorded in the sources (4000-500 cm⁻¹). The explanation of the spectrum is due to the interaction of light with the functional groups in the epoxy compound and the occurrence of stretching of the O-H, -C-H bonds, which vary in response to the frequencies of red and infrared light according to the chemical structure of the epoxy resin [11,12]. The IR spectra appearance small shift in spectrum revealed the interference between epoxy and titanium dioxide [13,14].

<table>
<thead>
<tr>
<th>Wave number (cm⁻¹)</th>
<th>Corresponding functional group</th>
</tr>
</thead>
<tbody>
<tr>
<td>~3423</td>
<td>O-H stretching</td>
</tr>
<tr>
<td>~3057</td>
<td>Stretching of C-H of the oxirane ring</td>
</tr>
<tr>
<td>~2965</td>
<td>Corresponds to asymmetrical C-H stretch of -CH₃ group</td>
</tr>
<tr>
<td>~833</td>
<td>Corresponds to –CH out of plane deformation in aromatic</td>
</tr>
<tr>
<td>~1036</td>
<td>Corresponds to asymmetrical aromatic C-O</td>
</tr>
<tr>
<td>~1618</td>
<td>Corresponds to C-C stretching vibration in aromatic</td>
</tr>
<tr>
<td>~1509</td>
<td></td>
</tr>
<tr>
<td>~1461</td>
<td></td>
</tr>
<tr>
<td>~915</td>
<td>Corresponds to epoxide ring vibrations</td>
</tr>
</tbody>
</table>

Table 1: Wavenumbers of FTIR peaks and the corresponding functional groups in neat epoxy.

3.2 UV/Visible Radiation Analysis

The typical normalized UV–Vis spectra of epoxy with filler TiO₂ content of 0, 1, 1.5, and 2 wt % composites are shown in figures 1-11. It is shown that the adding of the filler to the polymer lead to increase the intensity of peak. Critical analysis of UV-Vis spectra of epoxy/TiO₂ composites shows that the highest shift in absorption wavelength is in the range 350-600 nm.

3.2.1 Absorbance Spectrum

Figure 1 illustrates the absorbance spectra of epoxy composites with filler TiO₂ content of 0, 1, 1.5, and 2 wt%. It is clearly shown that the absorption increases with increasing percentage of TiO₂ added to the epoxy and shift peak of wavelength up from 320 nm in pure epoxy to 600 nm after add 2 wt% TiO₂, which has been assigned to the first excitation transition occurring in the epoxy/titanium dioxide composite [15]. This is due to the electronic transitions in the frame of the energy bands produced by TiO₂ because the titanium dioxide is a semiconductor material that absorbs visible light [16]. Yang et al. [17] carried out a similar investigation. They investigated how TiO₂ filling affected the optical characteristics of epoxy composites and found that the addition of TiO₂ caused the absorption peak of the composite shift toward the red and increased its absorbance. According to the studies' findings, the optical characteristics of epoxy composites are significantly altered when TiO₂ is added. The electronic transitions in the TiO₂-produced energy band frames are what caused the composite's absorbance to increase and its absorption peak to shift [17].
Fig. 1: The absorption spectra of epoxy with filler TiO$_2$

### 3.2.2 Transmittance Spectrum

Figure 2 shows the UV-visible transmittance spectrum of epoxy filler with TiO$_2$, as a function of wavelength. For pure epoxy, showed high transmittance in the range greater than 350 nm, while the rest of the grafted compounds showed a decrease in transmittance for wavelengths less than 600 nm, while wavelengths increases in the period greater than 600 nm with increasing TiO$_2$ concentrations [16]. In a study conducted by Yang et al. [17], they found that the addition of TiO$_2$ to epoxy composites resulted in a decrease in the transmittance of the composite. The decrease in the transmittance was attributed to the scattering of light by the TiO$_2$ particles [17].

Fig. 2: Transmittance spectrum of epoxy/ TiO$_2$ as a function of wavelength.

### 3.2.3 Refractive Index

The refractive index as a function of the wavelength of epoxy grafted with different percentages of titanium oxide Figure 3. The results showed that the reflectivity, depends on the UV/Vis spectrum, the reflectivity increases with the increase of TiO$_2$ concentrations in the region 500-900 nm, which is the transmittance region for pure epoxy, a decrease in the reflectivity values is also observed in the region less than 400 nm, which is the region where the absorption limit of pure epoxy is located due to the reflecting a mixture of visible wavelengths. In earlier research done by both El-Khodary et al. [18] and Abdel-Aziz et al. [19], the researchers discovered that the amount of TiO$_2$ improved the epoxy resin's refractive index. This is due to the fact that TiO$_2$, a highly refractive substance, improved the material's overall refractive index when it was combined with epoxy resin [18,19].

Fig. 3: Refractive index as a function of the wavelength for epoxy/TiO$_2$

### 3.2.4 Absorption Coefficient

Figure 4 shows the relationship between the absorption coefficient as a function of the UV and visible wavelength of epoxy filled with TiO$_2$, and the results showed a shift of the absorption limit of pure epoxy from the ultraviolet region to the visible region, with an increase in TiO$_2$ concentrations [16,20]. Das et al. [21] earlier study is referred to the optical and thermal properties of the resultant material were examined in this work in relation to the addition of titanium dioxide nanoparticles to epoxy resin. The researchers discovered that the amount of TiO$_2$ nanoparticles had an impact on the epoxy resin's absorption coefficient. The absorption limit of the epoxy resin was moved from the UV area to the Vis region as a result of the increase in the absorption coefficient of the epoxy resin with the concentration of TiO$_2$.

Fig. 4: Absorption coefficient as a function of the wavelength for epoxy with TiO$_2$
3.2.5 Extinction Coefficient

Figure 5 shows the relationship between the extinction coefficient of epoxy grafted with different percentages of titanium oxide as a function of the wavelength, where the extinction coefficient increases with the increase in the percentage of additions from oxide to epoxy, shift peak extinction coefficient from 320 nm for pure epoxy to 500 nm in epoxy with oxide. Then the extinction coefficient of saturation gradually increases with the increase in the wavelength as a result of the decrease in the distance between the particles of the mixture [20,22]. El-Khodary et al. [19] and Das et al. [21] are two other researches that looked at the impact of TiO$_2$ on the optical characteristics of epoxy resin. The researchers who conducted these investigations discovered that the extinction coefficient of epoxy resin increased as the amount of TiO$_2$ particles increased. But the authors also discovered that the sort of TiO$_2$ utilized had an impact on the epoxy resin’s extinction coefficient. When TiO$_2$ nanoparticles were employed instead of TiO$_2$ microparticles, the epoxy resin's extinction coefficient was greater.

![Fig. 5: Relationship between the extinction coefficient as a function of the wavelength](image)

3.2.6 Optical Energy Gap

Ultraviolet-visible (UV/Vis) spectroscopy has become an important tool to estimate the value of optical gap energy (E$_g$) in epoxy. The optical absorption edge can be correlated to optical gap energy (E$_g$) using equation 1. To study the changes in the optical energy gap (E$_g$) of epoxy compounds grafted with different concentrations of TiO$_2$, the relationship 1 was analyzed and the value of r recorded for all compounds used the differential function when more than one method of electronic transitions is expected, using computer program (Origin lab), where r determines the absorption behavior resulting from the nature of the electronic transitions between the energy bundles of the random structure [16], and it was found that it approaches the direct transitions where the value of r approaches 0.5 for all the prepared compounds, and by substituting the value of r in the relationship 1, and its graph is $(\alpha E)^{1/r}$ as a function of E [16,23,24].

$$\alpha (\omega) = \frac{B \left( \hbar \omega - E_{opt} \right)^r}{\hbar \omega} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where: $b = \text{constant depending on the band structure}$, $\hbar \omega = \text{photon energy}$, $E_{opt} = \text{optical energy gap for random material}$, $r = \text{constant}$ depends on the nature of electronic translations, $\alpha = \text{absorption coefficient}$.

For epoxy compounds grafted with concentrations of TiO$_2$, using the relationship 1, where the curves were obtained in Figure 6 and Table 2, it is shown that the value of E$_g$ decreases with increasing concentrations of TiO$_2$. This is due to the shifting of the absorption limit from UV to the visible region with increasing TiO$_2$ concentrations, and the resulting change in the electronic structure of the energy bands and the emergence of localized states, which reduced the optical energy gap width of the epoxy by the influence of TiO$_2$ impurities [25,26].

![Table 2: values optical energy gap for epoxy/TiO$_2$](image)

3.2.8 Real Dielectric Constant

Figure 7 shows the relationship between the real dielectric constant calculated from the relationship 2 as a function of wavelength, and the results showed an increase in the value of the real dielectric constant, with an increase in TiO$_2$ concentrations in the visible region while decreasing in the spectrum region (200 -350 nm), which is the region of strong adsorption of epoxy, the
value of $\varepsilon_i$ increased from (1.5-2) for pure epoxy in the visible region to (7-8) for the compound (epoxy + 1.5%wt), the true dielectric constant is related to the refractive index. In the relationship 2, and if the behavior of their curves in Figure 7 is compared, it can be said that they are similar, and both depend on the electronic polarization of the insulating compound [27,28], which increases with increasing concentrations of TiO$_2$.

$$\varepsilon_r = n^2 - K^2 \quad (2)$$

Where: $n$ = refractive index, $K$ = extinction coefficient.

![Fig. 7: Real dielectric constant as a function of the wavelength for epoxy with TiO$_2$](image)

**3.2.9. Imaginary Dielectric Constant**

Figure 8 shows the relationship between the imaginary dielectric constant and the wavelength of epoxy doped with different concentrations of titanium dioxide. The results show the dependence of the imaginary dielectric constant ($\varepsilon_i$) on the UV/Vis spectrum, but with a different behavior from the real dielectric constant ($\varepsilon_r$), where it increases in the high absorption region (320-400 nm), and decreases in the penetration region is greater than (500 nm), meaning that the imaginary dielectric constant depends on $K$, and the highest value of the imaginary dielectric constant is shown in the figure 8 as an expression of the peak energy absorption from the electromagnetic field. Due to the occurrence of a match between the frequency of the applied field and the movement of particles of the polar material, the latter works to track changes in the electromagnetic field, which is consistent with the optical properties of dielectric materials [29].

![Fig. 8: Imaginary dielectric constant as a function of the wavelength for epoxy with TiO$_2$](image)

**3.2.10 Results to Dielectric Properties**

The dielectric properties of epoxy compounds doped with TiO$_2$, which were studied, are capacitance (C), dielectric constant ($\varepsilon_r$), and capacitive reactance ($X_c$, at room temperature, 50 Hz) by instrument of a Dielectric Constant Measurement shown in Figure 9-11, to know the effect of each type of additive on the insulating properties and these compounds are: (epoxy pure) and (epoxy + 4%wt TiO$_2$). Figure 9 shows a diagram of the dielectric constant for epoxy compounds grafted with TiO$_2$ individually and collectively. The results showed that the dielectric constant values reached 2.3 and 6.09 Table 3 for pure epoxy, and epoxy with 4%wt TiO$_2$, respectively. The higher capacitance of epoxy/TiO$_2$ composites makes them useful for a variety of applications, such as capacitors, sensors, and antennas.

![Fig. 9: dielectric constant for epoxy pure and epoxy/TiO$_2$](image)
Table 3: results of dielectric properties for epoxy pure and epoxy with TiO$_2$

<table>
<thead>
<tr>
<th>Compound</th>
<th>d (mm)</th>
<th>Area (mm$^2$)</th>
<th>C (pF)</th>
<th>$\varepsilon_r$ at 50 Hz</th>
<th>$X_{C} \times 10^7$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>epoxy</td>
<td>3.7</td>
<td>134 X 62</td>
<td>45</td>
<td>2.301</td>
<td>7.07714084</td>
</tr>
<tr>
<td>epoxy + 4 % wt TiO$_2$</td>
<td>3.7</td>
<td>134 X 62</td>
<td>113</td>
<td>6.092</td>
<td>2.81833044</td>
</tr>
</tbody>
</table>

However, even though the relative permittivity of epoxy/TiO$_2$ composites is lower than that of pure epoxy, the capacitance of the composites can be higher. This is because the TiO$_2$ particles increase the surface area of the composite, which allows more charge to be stored. The relative permittivity of epoxy/TiO$_2$ composites is lower than that of pure epoxy because the TiO$_2$ particles disrupt the regular structure of the epoxy [28].

**Fig. 10:** capacitive reactance for epoxy pure and epoxy/TiO$_2$

The dielectric constant for these compounds at 50 Hz is called the static dielectric constant; Because it does not depend on the frequency change in the low frequencies range, and in comparison, which is consistent with previous studies in this regard [16,28].

**Fig. 11:** Capacitance for epoxy pure and epoxy/TiO$_2$

**Conclusion**

Through this study, the researchers reached many conclusions, the most important of which are:

- The dependence of the optical properties of all compounds under study on the UV/Vis spectrum, as these properties change with the frequency of the spectrum, and in general, it was found in all compounds that the values of transmittance, reflectivity, and refractive index increased, the real dielectric constant is in the visible spectrum region, while those values are lower in the short wave spectrum (200-350 nm) in the strong absorption region.

- Increasing the values of the optical properties (absorption, reflectivity, absorption coefficient, refractive index, real dielectric constant, imaginary dielectric constant) of epoxy resin with increasing concentration of TiO$_2$ additives.

- Decrease in the values of optical properties (transmittance, optical energy gap) for epoxy resin by increasing the concentration of TiO$_2$ additives.

- Oscillating decrease in the optical properties (absorption, reflectivity, absorption coefficient, extension coefficient, refractive index, real dielectric constant, imaginary dielectric constant) of TiO$_2$ in all regions of the spectrum.

- The addition of TiO$_2$ to epoxy composites can be used in many applications, including: Electronics (circuit boards and solar cells), coatings, adhesives, rubber, plastics and fibers, etc.

**Data Availability**

The original data are available upon request from the corresponding author.

**Competing Interests**

The authors declare that they have no conflict of interest.

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