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Synthesis and Characterisation of Polytetrafluoroethylene Composite for Electrical Insulation and Dielectrics

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Abstract. This work provides an experimental study to measure the electrical properties of Polytetrafluoroethylene polymer and how it improves through the process of mixing with different volume rates of Poly (methyl methacrylate) PMMA. The relationship of the actual dielectric constant with frequency for pure and doped models with different concentrations of PMMA (5%, 7%, 10%) and for a range of frequencies ranging between 1-1000 KHz, at the room temperature was investigated. The results show an increase in the dielectric constant of the composites compared to the pure models for all concentrations, which indicates that the polymers interaction gives support to the polytetrafluoroethylene infrastructure. The mixing process, also, leads to an increase in the values the imaginary part of the dielectric constant compared to the pure model, and this is due the significant increase in the number of dipoles resulting from the addition process which in turn led to increase the amount of energy lost due to rotation or friction of the dipoles with each other. This increase, in turn, led to a corresponding rise in the values of the loss tangent $\tan\delta$ and the AC conductivity of the models. The experimental results show a 90 % increase in the dielectric constant of the composite at 500 KHz compared to the pure Polytetrafluoroethylene, which provide a good electrical insulation material for electronic circuits.

1. Introduction

Polymeric materials contain in their individual cases many defects that cause a limitation of use such as fragility, excessive stiffness, and fracture. However, these defaults can be eliminated or at least reduced by mixing it with other types of polymers to enhance the desirable characteristics [1].

Polymers today have the greatest impact for enriching our technology, as they have entered all fields of science; scientific research groups and companies are in a competition to introduce new materials and to obtain alternatives to some existing materials. Improving their properties and the knowledge of their internal structure as well as modifying the identity of its elements by adding atoms of other elements to it or removing /mixing atoms are examples of the research trends in the field of polymers now a days [2].

Polymeric composites are the physical blending of two or more polymers that resulting a composite which has the desirable mechanical or electrical properties [3]. The wide uses of polymers in technological fields have made it of a particular importance. This importance resulted from the fact that polymers generally exhibit different variations in its electrical and isolating behavior when it dopped or mixed with other materials. However, some engineering problems still exist for polymers such as their lack of stiffness and strength compared to minerals. Therefore, several methods have been used to improve these deficiencies such as fiber reinforcement method [4]. In this method, fibers are either



continuous or random. Also, it can be in the form of particles, flakes, or laminates to improve the polymer properties.

Thin film technology [5] is the best way to give a clear idea of the physical properties of polymers; the term thin films is used to describe one or more layers of atoms of a thickness that does not exceed one micrometre. The concept of thin films is to arrange the atoms of that substance in two dimensions, so that the third dimension is very small (in the order of the nanometers) called the thickness. The main difference between a substance in a solid state and a thin-film state is that substance in the solid state neglects the effect of surfaces on its properties while in the case of thin films it is exactly the opposite i.e. the effect of surfaces on properties is the most dominant. Although there are many techniques used to produce thin films, it can be categorized under two technical methods known as the physical and chemical methods. Of the most important methods used is the thermochemical pyrolysis method where the films are highly adherent to the base and have high stability in their physical properties with the time [6]. This is the method used in this study.

This method is performed by spraying the solution of the material from which the films are to be prepared with the help of a high-pressure air on a hot base at a certain temperature depends on the type of material. The reaction between atoms of the substance and the hot base producing the films. Polymer blending is an important and widely used method to enhance the properties to obtain high dielectric constant compared to the values of these materials in its single case.

In this study, the electrical properties of some polymeric material that are known to be used as insulators are studied in order to obtain high dielectric values higher than that of any of those substances when they are in their single state.

2. Material used

2.1. Polytetrafluoroethylene (C₂F₄)

Also expressed as PTFE, is a synthetic polymer containing fluorine and is known commercially (Teflon) [7]. It is a non-flammable waxy solid produced from the polymerization of tetrafluoride. It needs at least 327 °C for melting and found with a density of 2200 kg/m³. It has a very low coefficient of friction, so it is used in devices that do not require lubricants such as the lining of the equipment that are used to store and transport strong acids and organic solvents. Also, it is used as an electrical insulating material in addition to its common use for coating materials that are used in cooking which does not require the use of fats or oils because the substance does not flow easily above the melting point.

2.2. Poly (methyl methacrylate) PMMA

It is a colorless, transparent plastic material with high flexibility and transparency with a high refractive index. The chemical formula is {CH₂C(CH₃) COOH₃}, melting point (213 °C), molecular weight (4000 gm / mol) and density (1.2 gm / cm³).

2.3. Dimethylformamide (DMF)

The molecular formula {C₃H₇NO}, molecular weight (73.1 gm / mol), boiling point 153 °C, and the density is (0.9445 gm / cm³).

3. Experimental setup

The density of the polymeric solutions is measured using a 25 ml density cannula and a digital scale type (Sartorius) with a sensitivity up to 1x10⁻⁴ gm by changing the mass to the size. While the gravimetric method was used to measure the thickness of the prepared films using the sensitive scale. The film is weighed before and after sedimentation, the difference is calculated, and the following relationship is used

$$d = \frac{\Delta m}{\rho A}$$

Where Δm is the difference between the weight of the film and ρ the density of the film in units of (g/cm²) and A is the film area.

Different weights were measured for polytetrafluoroethylene and PMMA. Polytetrafluoroethylene is preheated first in a glass baker until fusion and then add to it a calculated amount of PMMA with

different proportions (5, 7%, 10%) and the composite were heated with shaking to obtain a homogeneous solution. The solutions were thermally treated by placing them in an oven to gradually raise their temperature to 70 degrees, then gradually reduce its temperature to room temperature. The main purpose of heat treatment is to give the atoms the necessary kinetic energy to rearrange the crystal lattice, which leads to the regulation of the crystal structure of the material and thus reduce crystal defects in it. To study the electrical properties, an RLC circuit was used, and the measurements were made in a range of frequencies ranging from 1 to 1000 KHz.

4. Results and discussion

Figure 1 shows the relationship of the real part of the dielectric constant with frequency for pure and dopped models with different proportions of PMMA (5%, 7%, 10%) and for a range of frequencies ranging between 1-1000 KHz, at the room temperature. It is observed that the dielectric constant values of the dopped models increased significantly compared to the pure models for all concentrations, which indicates that the two polymers interaction gave support to the polytetrafluoroethylene infrastructure. Also noted that the dielectric constant values were high in the low frequency region up to 12 KHz where the dipoles find a sufficient time to rotate in the direction of the applied electric field. Then the values started to decrease with increasing frequency as these dipoles are no longer able to catch up with the electric field. After 175 KHz, the values of the dielectric constant were stabilized due to the restriction of the total polarization to the electronic polarization that does not change with frequency.

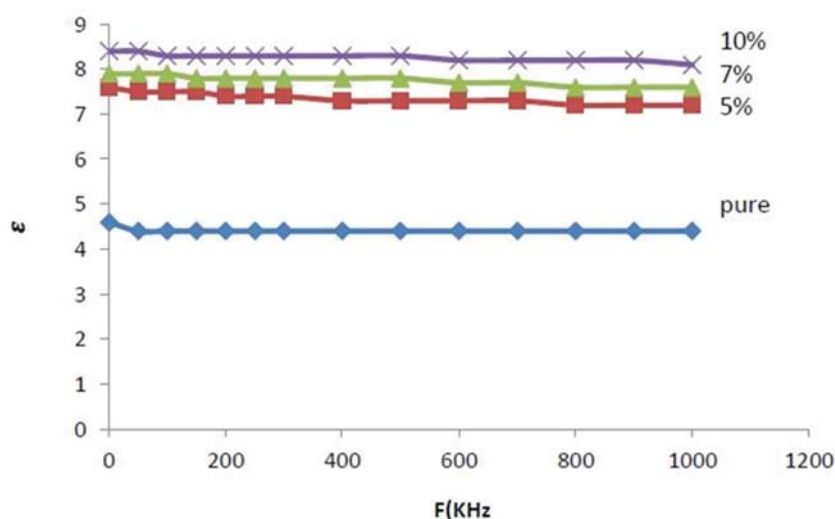


Figure 1. Relationship of the real part of the dielectric constant with frequency for pure and dopped models with different proportions of PMMA (5, 7%, 10%) and for a range of frequencies ranging from 1-1000 (KHz) and at the room temperature.

Figure 2 shows the change in the imaginary part of the dielectric constant with frequency. It shows that the mixing process led to an increase in the values compared to the pure model, and this is due the significant increase in the number of dipoles resulting from the addition process which in turn led to increase the amount of energy lost due to rotation or friction of the dipoles with each other. This increase, in turn, led to a corresponding rise in the values of $\tan\delta$ and the AC conductivity of the models as shown in Figure 3,4.

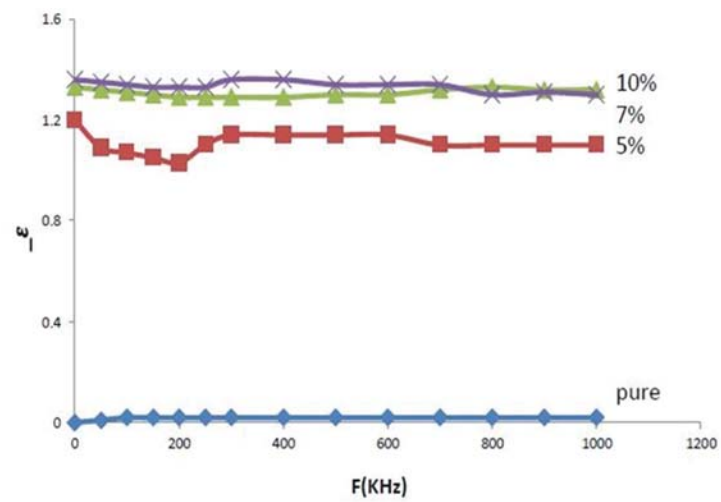


Figure 2. The relationship of the change in the imaginary part of the dielectric constant with frequency

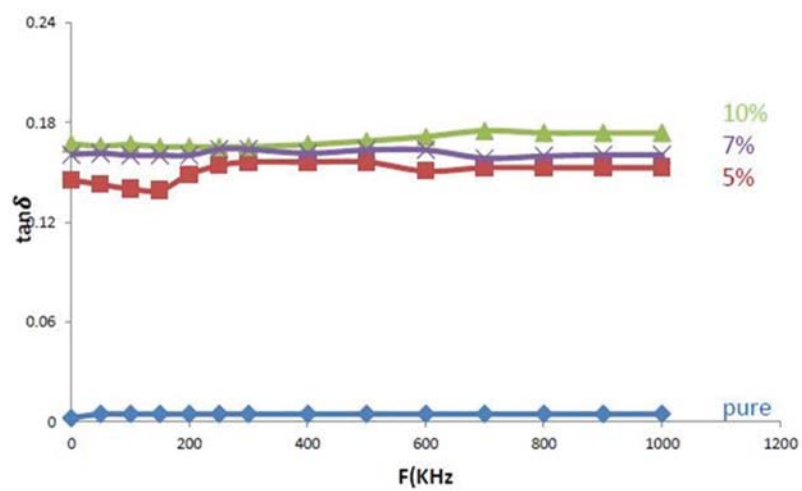


Figure 3. Relationship between $\tan\delta$ and frequency of pure and dopped polymer with different volume rates of PMMA.

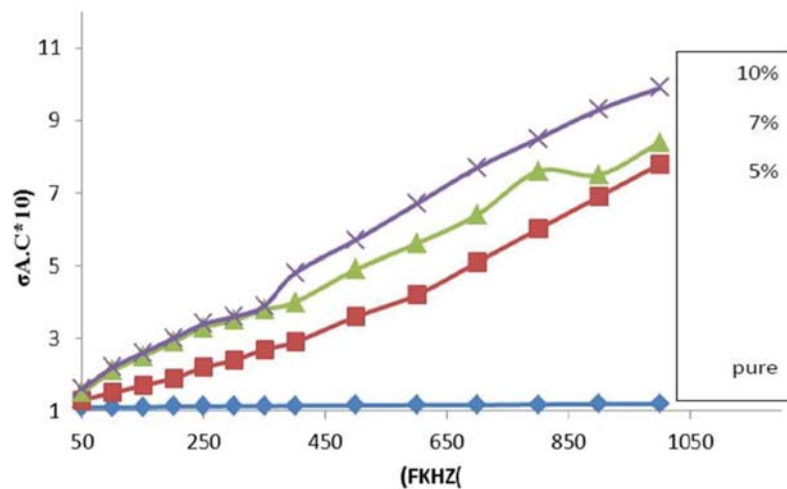


Figure 4. The relationship between the alternating conductivity and frequency of a pure and doped polymer.

Figure 5 shows the relationship of the real part of the dielectric constant with the pure and the doped model at the frequency of (500) KHZ, where it is noticed from that the doping process has a positive effect on the values of the dielectric constant and the highest values was at 15%, as it was around (9) (at the low frequency region). Taking into account that the value of the real part of the dielectric constant of the pure polymer is around 4.52, then the resulted value in fig.5 shows a big enhancement due to the process of mixing the pure polymer with PMMA. Enhancing the dielectric constant for the composite improves the refractive index and allows for using it with the emerging applications such as in optical ring resonators to control the resonance frequency by changing the cavity refractive index [8].

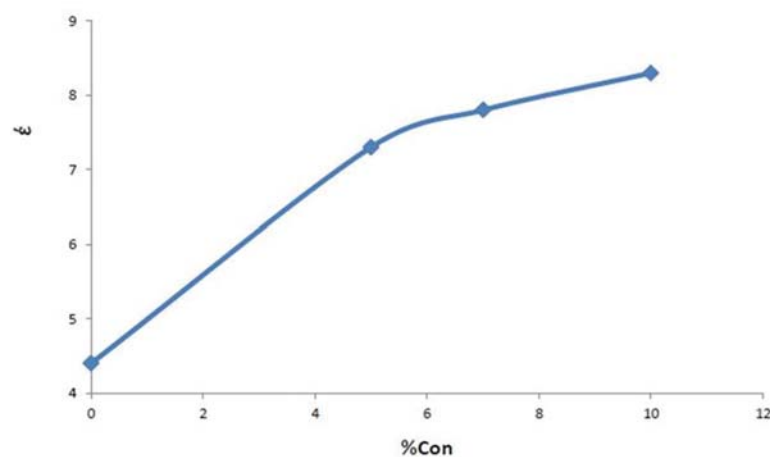


Figure 5. The relationship between the dielectric constant and different concentrations of pure polymer doped with PMMA at different rates.

5. Conclusion

Polytetrafluoroethylene composites are synthesized and tested experimentally using different volume rates of PMMA to produce good insulators for electrical circuits applications. The thermochemical pyrolysis method, where the films are highly adherent to the base and have high stability in their physical

properties with the time, is used in this work. Polytetrafluoroethylene and Poly (methyl methacrylate) are mixed at the room temperature with different volume rates and tested for different frequencies. The real and imaginary parts of the dielectric constants are calculated and presented for different frequencies and concentrations. The results show a high increase (more than 90%) of the dielectric constant of the composite compared to the pure model at 500 KHz which provide a good insulator for electrical and electronic circuits.

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