Study the improvement in the dielectric strength of (UPR/MgO) nanocomposites

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Abstract. This work focuses on the preparation of polymer matrix nanocomposite materials by hand lay-up molding which was prepared from the unsaturated polyester resin as matrix reinforced by nanoparticles of Magnesium Oxide(MgO) with particle size (54.19 nm) and weight fraction (0,1,3,5,7,10 and 15)%. Dielectric strength for the prepared samples was studied; the results of tests have shown the increase in the dielectric strength with increasing the weight fraction of additive (MgO) and also with the increases in the rate of voltage. The effect of the cycle's number on the dielectric strength has noticed clearly after the first cycle. The images taken for the electric breakdown points by using optical microscopy has shown the sample coaled in the electric breakdown area as a result of polymeric chains of unsaturated polyester (UPR) destroyed, and there is an appearance of microcracks as a result of electric breakdown extends directly from the point of electric breakdown.

Keywords: polymer nanocomposites, unsaturated polyester resin, MgO nanoparticles, dielectric strength.

1. Introduction

Polymer nanocomposites are materials that have polymer as a matrix material and nanoadditives are used as reinforcement material. The additives can be one-dimensional (nanotubes and fibers), two-dimensional (layered materials like clay) or three-dimensional (spherical particles). Polymer nanocomposites have been gaining considerable attention both in academia and in industries, due to their outstanding mechanical properties such as high elastic stiffness and strength with a small concentration of nanoadditives, the other excellent properties of polymer nanocomposites are barrier resistance, flame retardancy, wear resistance, magnetic, electrical and optical properties [1]. Many materials such as polymers and ceramics have valence electrons strongly associated with the nuclei of their atoms, so, and without the presence of free electrons, they have a very weak conductivity "According to" the theory of energy bands for solids, the energy gap is large between the valance and conduction bands and the valence band is completely filled with electrons at absolute zero temperature [2].
The depth (energy difference) of this gap may be (10eV) and above, where even if it applied an electric field, the electrons do not move a large number in one direction, each electron is moving towards a certain to reverse invert another electron is moving in the opposite direction of movement because the band is completely filled, such as these materials are called (Dielectrics) [3, 4]. Several reports have been carried out about the investigated such properties as in (2012) Ram Avatar Sharma, et al. have studied the effect of nano and micro silica on the electrical property of Unsaturated Polyester Resin (UPR) composites. The value of the dielectric strength is slightly higher in nano-silica (UPR) composites when compared to micro silica-based composites, dielectric constant keep decreasing. The dissipation factor decreases up to the nano-silica loading of 1.5 percentages [5], as well as in (2016) Najwa. J. Jubier studied some mechanical and physical properties of Polyester/Granite composites by hand lay-up method with different weight fraction, it was found that the values of thermal conductivity and dielectric strength increase with increasing granite content, but it decreased only at weight percentage 20% [6]. Also In (2017) Duraid has studied the effect of addition Magnesium Monoxide (MgO) on the thermal and electrical properties of Iraqi Porcelain with different weight percentages (0, 5, 10, 17, 23, and 30) %. The best results for specific heat capacity and thermal conductivity are for mixture with (30%MgO), thermo-compressive strength for mixture with (23%MgO) and dielectric strength for mixture (10%MgO) [7]. In this research, the UPR/MgO nanocomposites were prepared with different weight fraction (0, 1, 3, 5, 7, 10 and 15) % of nanoMgO. The dielectric strength of these samples was investigated.

2. Dielectric Breakdown Strength

Dielectric breakdown strength is defined as the highest voltage which samples can stand before they fail electrically, divided by sample thickness, or the magnitude of the electric field required to causing a dielectric breakdown. When applying a strong electric field on the insulator higher than the value of the specific critical, a large number of electrons may suddenly be excited to energies within the conduction band. As a result, the current through the dielectric by the motion of these electrons increases dramatically, sometimes localized melting, burning, or vaporization produces irreversible degradation and perhaps even failure of the material, so that the insulation properties will be lost for the insulator and becomes a conductor. So the voltage that occurs when the breakdown is called (U_{br}), (Breakdown voltage) when divided by the thickness of the samples (h). We obtain (E_{br}) dielectric strength in units (kV/mm) or (V/cm) as in Eq. (1) [8].

\[ E_{br} = \frac{U_{br}}{h} \]

A breakdown can be seen in the material by one of the following cases:

Case one, hole in the sample, which occurs when reach the real electrical durability of the insulation.

Case two, burn or melt, which can occur when the material is heated locally and breakdown [9]. There are several factors affecting on the thermal breakdown voltage of the polymers like geometrical structure, size (especially thickness), thermal conductivity, specific heat of polymer, environment heat (ambient), the rate of increase in voltage, the value of the (tanδ) and change its with temperature, and relative dielectric constant [10]. The main types of breakdown that occur in insulators are intrinsic breakdown and electrothermal breakdown.
3. Materials and Method

3.1. Experimental

Use unsaturated polyester resin (UPR) made by (Polres) company from Turkey. This resin in the form of a viscous liquid, transparent purple color at room temperature and converts from a liquid to the solid state by adding Hardener Methyl Ethyl Ketone Peroxide by rate of 2 % which manufactured by the same company. The Magnesium Oxide (MgO) nanoparticles (NPs) utilized in the present study have been produce from (Skyspring Nanomaterials, Inc. USA) (99% purity as per suppliers’ data). Atomic Force Microscopy (AFM) was used (SCPMS canning Probe Microscope) to measure the average particles size, surface roughness and Root Mean Square (RMS) of MgO nanoparticles as shown in Table 1. Fig. 1 shows image (3D-AFM) of nanoparticles MgO and particles size distribution. Samples of pure unsaturated polyester resin (UPR) and (UPR) with a different weight percentage of MgO nanoparticles (0, 1, 3, 5, 7, 10 and 15%) were prepared by hand lay-up technique and used ultrasonic in the mixing process. All content mixed thoroughly before casting, then the samples were left at room temperature for (24) hours and then for post-curing the samples were left for (1) hour in an oven at temperature 50 °C.

Table 1. Average particles size, surface roughness and root mean square values of nanoparticles MgO.

| Material | Average particles size (nm) | Surface roughness (nm) | RMS | Peak to peak (nm) |
|----------|----------------------------|------------------------|-----|------------------|
| MgO      | 54.19                      | 2.9                    | 3.36| 12.3             |

Figure 1. AFM of nanoparticles MgO; (a) Granularity distribution of nanoparticles; (b) 3D image AFM.
The dielectric strength measurement was carried out by (BAUR-PGO-S3) Germany origin with high voltage supplier in the voltage range (0-60 kV) and frequency (50 Hz). The instrument contains liquid with a high dielectric strength (voltage transformer oil (40kV/mm)) to prevent transmittal of the circumstantial spark (Flashover), in addition to rise speed of liquid inflammation, and the oil must change to prevent the ionization of liquid which leads to inaccuracy measurement. It also contains copper poles of good electrical conduction and spherical shape, its diameter about (2mm), as shown in the Fig.2, so the sample put them which are embedded in oil with make sure of touching poles with the sample surface then applying voltage through the sample that occur the breakdown voltage. After knowing the area that breakdown happens which can be distinguishing according to the damage that occurs because of the breakdown. Fig.3 shows the prepared samples.

4. Result and Discussion

4.1. The voltage elevating average

Figure 4. Explains the change in the dielectric strength with the voltage elevating average of polymer nanocomposite (UPR / MgO) at different weight ratio (0, 1, 3, 5, 7, 10 and 15) %. It is observed that the increase of dielectric strength with the increase in the voltage elevating average as the voltage elevating average (0.5kV/sec) leads to increase in heat raised from the leakage currents, where the applying voltage for a long time increases the possibility of occurrence of the electro thermal breakdown. Since the insulating materials decrease electrical resistance due to increased local temperature, so decrease will appear in dielectric strength with decreasing in the voltage elevating average.
The reasons behind the decrease of dielectric strength with a decrease in average time to increase the voltage occur cumulative effects of the collision (chemical and electrochemical) and the corrosion which in turn destroy the materials and speeds up the breakdown by heating. These low values are the same operation values when used insulators in practical applications. We note abnormalities of some points about the general behavior and the reason is attributed defects within the composite material or homogeneous weaknesses of each testing points in the sample. As we note that the electric spark penetrates the insulator material at the time of breakdown which passes through those points that represent points of weakness and this is called the (effect of treeing) in the electric breakdown [10,11,12].

4.2. The effect of the number of periods

The test of dielectric strength changes with the number of periods, which is one of the tests that can know the possibility of using electrical insulators with the electric breakdown and recycle it again in the practical applications that need less voltage. Figures (5 and 6) describe the change in dielectric strength with the number of periods of polymer nanocomposite (UPR/MgO) at the same previous weight ratio at (0.5 and 5)kv/sec. it is noted a decrease in the dielectric strength after the first cycle for all prepared samples, the possible reason is attributed to the large chemical changes that appear with the diffusion of electric spark, because the test leads to burn the material or puncture it at the point of test and therefore the material loses the dielectric property and become conductive. The anomaly tests of some points for the general behavior of the test because the defects have arisen in the prepared samples of nanocomposites, and the effect of thermal and mechanical to the voltage on the sample sometimes may lead to a reduction in the thickness of the sample, or even puncture it, therefore oil enter between the poles which effect on data of examination. There is a significant change in the possibility of using the insulating materials after the first round of electric breakdown, as sometimes a decrease in dielectric strength in the second round to half value of the first round, which causes a significant decrease up to 90% in the value in the first one as in Figure 5.
Figure 5. Dielectric strength versus No. of periods at (0.5kv/sec).

Figure 6. Dielectric strength versus No. of periods at (5kv/sec).
4.3. The effect of additives rates on the dielectric strength

Figure 7 describes the change in dielectric strength with different weight of nanoMgO. It is noted that the dielectric strength of nanocomposites is higher than the polymer and it increases with the increase in the ratio of addition and this result is agreeing with E. Tuncer [13], because the ceramic materials have higher electrical insulation as compared with polymeric materials and the use of nanoparticles lead to the spread within the polymer mixture and thus the high density of widespread nanoparticles, which leads to impeding the passage of current and this result agrees with Saikat[14].

![Figure 7. Dielectric strength versus additives rates of nano MgO.](image)

Figure 8. represent images taken for the electric breakdown points by using optical microscopy. The images have shown that the sample coaled in the electric breakdown area as a result of destroying of polymeric chains to unsaturated polyester (UP), and the formation of microcracks as a result of electric breakdown which extends directly to the point of electric breakdown. The optical microscope pictures show that there are micro-cracks were larger and more sinuosity and distortion of the samples, This is because the great convergence of nanoparticles, diffusing, dispersal, high homogeneity, and high stable distribution in all directions, that nanoparticles enjoyed and the most important distinguishing of nano reinforcement.
Figure 8. Represent optical microscopy images for the electric breakdown points.
5. Conclusion

The dielectric strength increases with the increase rate of voltage for polymer nanocomposite, while it decreases as the number of the period increased. The dielectric strength also increase when the (MgO) added to the matrix material (UPR), until to reach its heights value at addition rate of (10%) (21.6kV/mm), while at addition (15%), it decreased to (20.8% kV/mm), this is due to the emergence of weak areas in the inter phases, which are areas of low breakdown strength and the presence of aggregates of nanoparticles in addition to the existence of micro bubbles that are difficult to get rid of them.

6. References

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