The Effect of Colemanite on Dielectric Properties of Polymers

Aysel ERSOY[1], Mukden UGUR[1], Ayten KUNTMAN[1], Ahmet MEREV[2], Berrak ÖZTÜRK[3]

[1]Istanbul University, Faculty of Engineering, Dept of Electrical & Electronics Engineering, 34850, Istanbul, Turkey
aersoy@istanbul.edu.tr   mugur@istanbul.edu.tr   akuntman@istanbul.edu.tr
[2]TUBITAK National Metrology Institute (UME) Gebze Yerleskesi 41470 Gebze, Kocaeli, Turkey
ahmetm@ume.tubitak.gov.tr
[3] Istanbul Kultur University, Department of Electronics Engineering, 34156, Istanbul, Turkey
bozturk@iku.edu.tr

Abstract

The aim of this study is to investigate the effect of colemanite on dielectric properties of polymers. In this study polyester is used as the base polymer insulator. The electrical conductivity, relative permittivity and dissipation factor (tanδ) of polymers are measured as a function of colemanite concentration in polyester samples. After dielectric measurements are completed, breakdown strengths are evaluated for each concentration. Experimental measurements show that adding colemanite to polyester has an influence for good in samples which is going to be used in electrical applications.

1. Introduction

Electrical characteristics of composites made from different fillers dispersed in polymeric materials have been the subject of many investigations [1-6]. Polymeric insulators are widely used due to economical reasons and also their superior electrical and mechanical properties. Several studies to evaluate the electrical properties for borax added polyester samples have been done recently [1-4]. In our previous studies, it has been shown that adding boron minerals to polyester increase the lifetime of samples under accelerated surface aging tests according to ASTM D2303. Also in that study it was noted that composite samples prepared with borax were degraded as erosion rather than tracking but colemanite addition did not change the surface degradation behavior of polyester sample like other boron minerals [1].

Previous studies with borax added composites have shown that there is an optimum value for borax concentration in the sample [2-3]. The contact angle and surface tension values of polyester samples were decreased with increasing the borax concentration which is very important for outdoor applications [4].

During the last couple of years, several studies have been made on the application areas of boron minerals. Colemanites are being used in PVC polymers for more than three decades to improve its flame retardant characteristics and in ceramics to gain ferroelectric properties [7-9].

In this study initially the electrical conductivity, relative dielectric permittivity, and dissipation factor (tanδ) of colemanite added polyesters are measured. At the last stage the electrical strength of polymeric insulators sintered with different colemanite minerals are investigated.

2. Experimental

All samples are prepared from an unsaturated polyester resin with colemanite as a filler in concentrations 0.5 %, 1.0 % and 2.0 % by weight. When formed with colemanite powder which has a diameter of lower than 35 μm, final samples are transparent like pure polyester samples. This means that colemanite mineral disperse properly in polyester resin.

The electrical strength of test samples has been measured at power frequency (50 Hz) according to the IEC 60243-1 test standard by using the electrode configuration shown below in Figure 1 [10].

Typical dimensions of the circular discs used for measurements are 100 mm diameter and 3 mm thickness. Test object has been placed between brass electrodes. For each filler concentration 5 samples are used and the average values of these measurements are taken to draw the graphics given in this study.
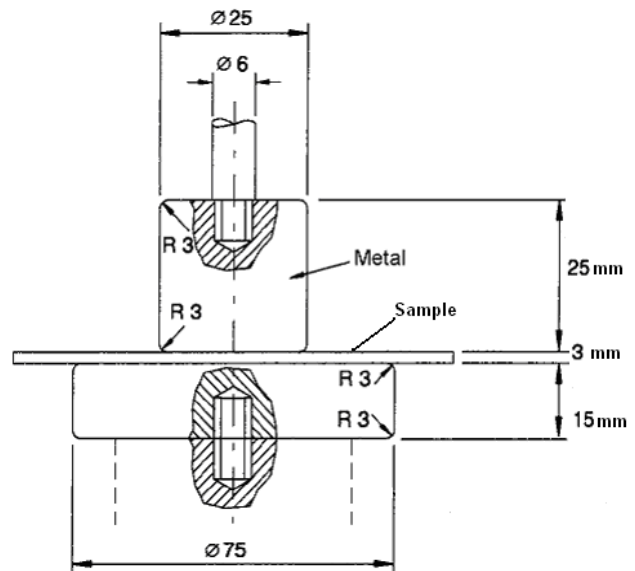

Figure 1. Electrode configuration

These electrodes together with test sample has been called as C_x and shown in Figure 2 as a part of test configuration. By using a DSP based digital capacitance and tan δ measuring system

(LDIC of brand and LDV-5 of model), the dielectric properties of test samples has been measured at power frequency [11].

The basis concept of the measuring setup is evident Figure 2. The bridge circuit consists in principle of a measuring branch and a reference branch as conventional measuring setup by Schering. The measuring branch can be regarded as a voltage divider with the capacitance of C_X of the test object and the low voltage capacitor C_M of the measuring impedance. The reference branch contains the high voltage standard capacitor C_N in series with the low voltage capacitor C_R. For the accurate measurement with this system, the actual capacitance values of C_M and C_R is well known.

For measuring C_X and tan δ the bridge has not to be balanced completely, as in the case of conventional circuits. The both low voltage capacitors C_M and C_R are adjusted in such a way, that the divider ratio of each branch is in the same order. In this measuring system, an ideal bridge balancing like Schering is not required, because the tan δ results from the determination of the phase angle between the both voltages on the across the low voltage capacitors C_M and C_R. Those voltages are digitized by the battery-powered high precision Sensor-1 and Sensor-2. Each sensor is equipped with a high impedance, low-noise amplifier, followed by a fast 16 bit A/D converter and electro-optical interface. The digitized signals are transmitted via fiber optical links (FO) to the Computer for further processing. The phase difference of the base frequency of the test voltage is calculated by using Fast Fourier transformation (FFT). This ensures the determination of the dissipation factor tan δ at extremely high accuracy. Additionally, the capacitance C_X of the test object is determined by calculation the divider ratio of the measuring branch.
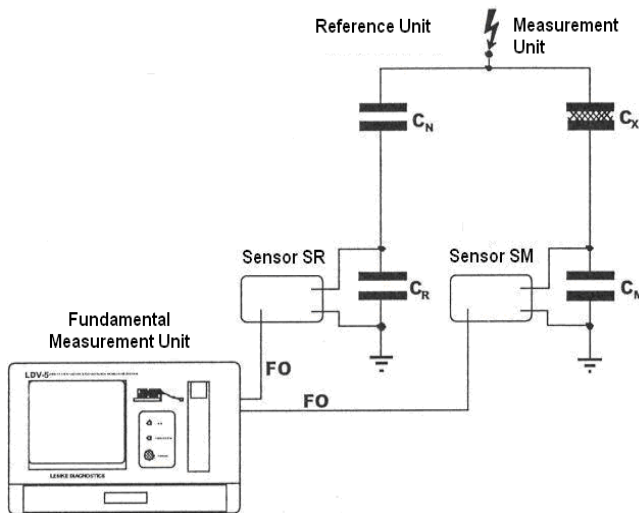

Figure 2. Principle scheme of measuring system

Breakdown voltages of the polyester samples with different filler content are determined according to IEC 60243-1 standard. In order to ensure adequate strength of the samples, the tests are performed in a vessel which is filled with silicon oil. To evaluate the breakdown voltage, applied voltage is raised up to the electrical strength voltage of the samples. According to the IEC 60243-1, the rate of rise is chosen among the values of 100 V/s, 200 V/s, 500 V/s, 1.000 V/s, 2.000 V/s or 5.000 V/s. In this test the rate of the rise is chosen as 2.000 V/s because it is recommended by standards for moulded materials.

3. Results and Discussion

1.14 ± % 0.5 kV, 50 Hz test voltage is used to measure the dielectric properties of composite samples. The change in electrical conductivity according to colemanite concentration is given in Figure 3. Increasing the filler content in polyester samples also increase electrical conductivity.
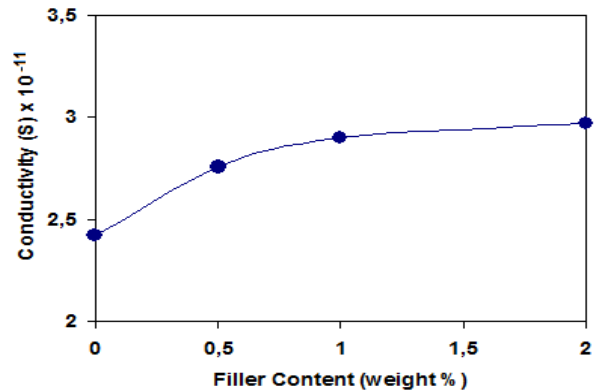
Figure 3. Dependence of colemanite content on electrical conductivity.

Our test results and several studies performed to measure the dielectric constant of colemanite added composites indicate, that the results of Gavrilova's study can be accepted as reference for dielectric constant measured at 50 Hz applied frequency. Since the relative permittivity for colemanite at 1 kHz, 20 ºC is measured as 75 prior to Gavrilova's study [9], there is an expectation for an increase in relative permittivity after adding colemanite to polyester composite sample. Our measurements, as given in Figure 4, indicate that the change in permittivity is not constant with respect to the filler content. Up to a certain level (1.0 %) the relative permittivity increases considerably, however at higher filler concentrations such as 1.0 % - 2.0 %, the slope changes remarkably and after 1.0 % filler content, the permittivity is almost stable at 9.5.

There is a simple relationship for dielectric constant of composites with volume fractions of the components in the composite. This equation is:

$$\varepsilon_{composite} = \frac{\varepsilon_1 V_1 + \varepsilon_2 V_2}{V_1 + V_2} \tag{1}$$

Here V_1 and V_2 refers the volumes of polyester and colemanite in the composite sample respectively. $\varepsilon_{composite}$, ε_1 and ε_2 refers composite's, polyester's and colemanite's relative permittivity, respectively. In this study we use two components to make our composite. The density of polyester is 1.4 g/cm^3 and the relative permittivity for polyester is 9.189 from our measurements for pure polyester sample. The density of colemanite is 2.423 g/cm^3 and the relative permittivity of colemanite used in this study is taken from Gavrilova's study as 75 [9]. Using the equation above, the theoretical and the

experimental relative permittivity of the composite is given in Table 1. Although the theoretical variation of relative permittivity is linear, the experimental variation seems slightly different. Since the preparation and the curing procedure for all of the composite samples is same, it seems necessary to make further chemical studies in order to understand this behavior.

Table 1. The theoretical and experimental relative permittivity values for polyester samples with different filler concentrations.

| Filler content (weight %)	Relative Permittivity	
	Theoretical	Experimental
0	9.189	9.189
0.5	9.379	9.466
1.0	9.568	9.397
2.0	9.942	9.466
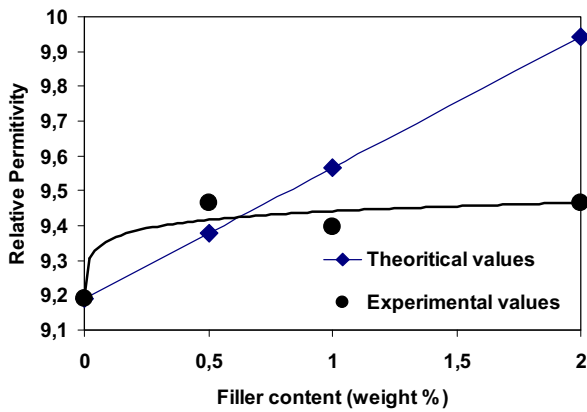
Figure 4. Dependence of colemanite content on relative permittivity.
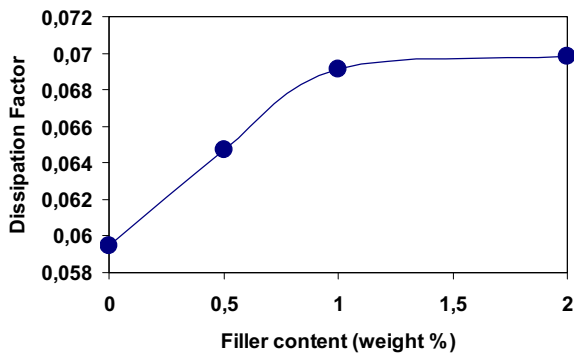
Figure 5. Dependence of colemanite content on dissipation factor.

Dissipation factor measurement for polyester samples according to filler weight is given in Figure 5. The sharp increase in dissipation factor continued through 1.0 % colemanite added sample, however there is a very small increase between 1.0 % and 2.0 % colemanite added samples.

The breakdown voltage of composite samples versus filler concentration is given in Figure 6. Breakdown voltage of samples are improved by increasing the colemanite concentration, hence according to these results it is possible to claim that some electrical properties of polyester can be increased by adding colemanite. However increasing the colemanite concentration also alters the dielectric characteristic of polyester such as conductivity, relative permittivity and dissipation factor. With these results it is clear that there is an optimum value for colemanite addition to polyesters. From this experimental study it can interpreted that 0.5 % - 1.0 % colemanite as a filler considerably increases electrical properties of polyester without a significant reduction in mechanical properties.
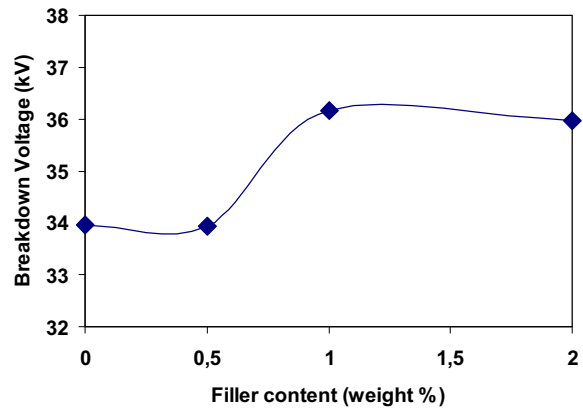
Figure 6. Dependence of colemanite content on breakdown voltage.

4. Conclusion

Based on the experimental studies carried out on polyester resin with different colemanite concentration, the following conclusions are drawn with respect to the dielectric measurements of composite:

- It is possible to claim that colemanite can also be used as filler in polymeric insulators.

- The optimum filler percentage for relative permittivity and breakdown strength seems to be between 0.5 % - 1.0 %, although the electrical conductivity and dissipation factor are also increased at this level.

- Increasing the filler content in polyester improves the breakdown voltage of composite.

As is the case for all other electrical applications, further studies are required to determine whether colemanite has a future in the evaluation of polyester materials.

5. References

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