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Research paper

Study of Factors Affecting the Dielectric Strength of [Ep/Z_rO_2 – y_2O_3] Nanocomposites

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Abstract

A nanocomposite material was prepared from epoxy resin reinforced by nanoceramic powder [Nano Zirconia – Yttria, (Z_rO_2 – y_2O_3) (70-80nm)], with several weight ratios (1.5, 2.5, 3.5, 4.5 Wt%), the research samples were prepared according to the standard specifications in different thicknesses (1, 1.5, 2, 2.5mm). The effect of addition rate (Wt%) was studied in addition to the thickness, number of cycles, and average of voltage increase, on the dielectric strength (E_{br}) for the composites before immersion, then, the effects of immersing the composite material in distilled water were observed also in NaOH and HCL diluted solutions (0.5 N) were observed .The test results revealed an increase in(E_{br}) with increasing the addition of (Z_rO_2 – y_2O_3) [(from 27.8 kv/mm for a ratio of 1.5 Wt% to 33.4 kv/mm for a ratio of 4.5Wt% at the average of voltage increase 0.5 kv/s) (and from 31.4 kv/mm for a ratio of 1.5Wt% to 36.7 kv/mm for a ratio of 4.5Wt% at the average of voltage increase of 5kv/s)], and with increasing average voltage increase, on the contrary,(E_{br}) decreases with increasing the sample thickness, number of cycles, and immersion in distilled water and chemical solutions (with immersion period) noticing that the chemical solutions effect was greater than that of the distilled water.

Keywords: *Epoxy Resin, Zircon-Yttria, Nanocomposite, dielectric strength, Breakdown Voltage*

1. Introduction

Polymeric composite materials are the most important materials that meet the requirements of technological and industrial developments , due to its high characteristics , such as , light weight, good strength , chemical stability, resistance to the surrounding conditions , and the fact that it has high electrical and thermal insulation ,depending on the additive materials , in addition to the ease of manufacturing .In the forefront of such materials is the epoxy nanocomposites .The nanocomposite materials are defined as composites in which they're reinforced by nanomaterial (10^{-9} m) and this nano material can be categorized into three types: three dimensional substance such as nanoparticles, two dimensional substance such as nanofibers and one dimensional substance such as nanoclays [1,2].
Polymers and ceramic materials have very low electric conductivity due to lack of possessing free electrons, huge energy gap, and its valance electrons having a very strong bond with its nucleus [3].

1.1.Dielectric Strength:

Dielectric strength refers to the ability of an insulating material to resist the utmost voltage imposed on it for a long duration without failure, the voltage at which failure occurs is known as Breakdown Voltage [4]. The failure of an insulator is the loss of the insulator to its electric insulation property and its transformation into conductor, the maximum electric field applied on the insulator at which failure occurs is called dielectric strength (E_{br}) [5], whereby applying high voltage on the insulating material higher than a specific critical value causes relatively high electric current flow, and so the material loses its insulating property and transforms into conductor. Dielectric strength is measured by electric field (E_{br}), which is the filed at which the insulator material fails), [6].according to the equation (1):

$$E_{br} = V_{br} / t \quad (kv/mm) \tag{1}$$

Where:
V_{br}: maximum applied voltage
t: thickness of sample

Failure is indicated on an insulator by puncture, smelting or burning in the insulator material, where the point of failure in an insulator produces electrical spark that could burn, smelt, or break the sample and the electrodes as the mechanism of failure of the solid insulator changes with increasing in the time of the voltages, shown in Fig. (1), [4,7].

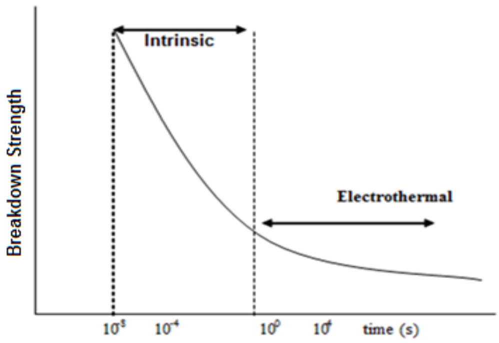


Fig.1: Variation of Electrical Breakdown with Time of Applied Voltage

Dielectric strength relies on many factors such as crystalline structure, imperfections and impurities found in the insulator material, number of electrons, and external factors such as the shape of the electrodes used to shed the electrical voltage, nature of the external surface and the test conditions which include temperature and humidity, source frequency and time period of applying voltage on the insulator and number of cycles and thickness of the sample. There are two main kinds of electrical breakdown in insulators: Intrinsic breakdown and electrothermal breakdown [8, 9, and 10].
When an alternating voltage is applied on a dielectric material, it receives several phenomena in the insulator, such as polarization and electric conduction, where increasing the voltage on the insulator material increases leakage currents and the alternating current of the alternating voltage. When the applied voltage is at its greatest value, causing the breakdown of the insulator material, where the conductivity current is leaking increasingly in the material and then the voltage start to decrease because of the insulating material low resistance [11].

1.2.Intrinsic Breakdown:

It is the collapse that is caused by the influence of the electric field when the voltage exerted on the insulator affects it for very short period ($\approx 10^{-8}$ s), hence, the so-called intrinsic field strength is created with the absence of other external influences as the intrinsic breakdown does not rely upon the shape and the sample dimensions, the nature and engineering of electrodes. its (Ebr) depends poorly on the frequency of the voltages and temperature and is therefore a breakdown of an electronic nature. The intrinsic breakdown occurs when the self-intensity can be reached when the insulating electrons acquire energy from the exerted field enough to overcome the forbidden gap energy between the valence band and the conduction band [12].

1.3.Electrothermal Breakdown

When an effective voltage applied to the insulator, it releases heat from the insulator because of loss due to leakage currents. The amount of heat produced locally is greater than the heat dissipated due to the poor thermal conductivity of insulator materials, then the effect of fusion, penetration and cracking in the insulator is apparent and depends on the frequency of the voltages and the long time period impact [8, 13].

2. Experimental Procedures

An epoxy resins (type Polyprime EP) had been utilized as a matrix material, and it is a transparent liquid that can be converted to solid state by adding its hardner with a ratio of 1:3 , and the ceramic powder nano Zirconia-Yttria [Yttria – stabilized zirconia (YSZ) ($ZrO2$ – Y_2 O_3) with particle size (70 – 80nm) used as a reinforecement material as well.
To prepare the composite material, the nanopowder (Z_rO_2 – y_2 O_3) was added to the epoxy resin at weight ratios of 1.5, 2.5, 3.5, 4.5 Wt% and after preparing the samples according to the standard specifications (ASTM) and perform the necessary heat treatment to be as perfect as possible and free of pores and cracks, and with different thicknesses (1, 1.5, 2, 2.5 mm).
A test was carried out for the (E_{br}) of the prepared composite samples using a machine type (BAUR – PGO – S – 3) from a German manufacturer where samples are submerged in oil possessing high dielectric strength (40 KV/mm), to overcome the flashover phenomena, and by applying the voltages on the sample surfaces until a failure of the insulator occurs, and using a low voltage rise rate 0.5kv/s and high 5kv/s for five cycles, and by studying the influence of the ratio of addition and thickness and rate of rise of voltages and the number of cycles on the dielectric strength before and after immersion in distilled water and NaOH and HCL diluted solutions (0.5N) to observe the effects of mentioned solutions on the insulation strength . The dielectrical strength for the samples was measured according to the equation (1).

3. Results and Discussion

Before immersing , the results showed that (E_{br}) increased with the increase in ratio of (Z_rO_2 – y_2 O_3) added to the polymer, Fig.2,due to increased bonding between the matrix and the reinforcement materials, which impedes the passage of electrical leakage currents and the dispersion of the carrier charges and this leads to increase the dielectric strength of the material [14,15]. The higher the rate of voltages, the higher is the insulation strength and this represents the intrinsic dielectric breakdown, and in the case of a low rise rate, the state of electrothermal breakdown occurs because of the heat emission from the point of contact between the sample and the electrodes due to the insulation loss because of leakage currents which leads to a decrease in the dielectric strength [16].

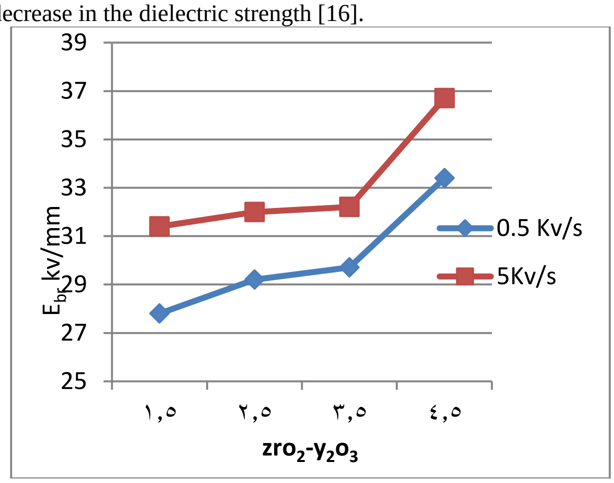
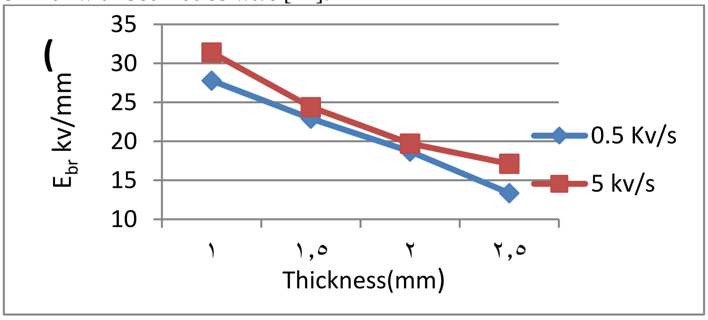


Fig.2: variation of E_{br} with different Wt % additives

Fig.3 shows that increasing sample thickness led to a decrease in dielectric strength of the composite, The greatest amount of reduction in(E_{br}) was in case of low applied voltage (0.5kv/s), noting that the increase rate in the breakdown voltage was not proportional to the increase in thickness of the material. However, increasing thickness of the sample leads to delaying the passage of the charge carriers and thus obtaining the electrothermal effects due to the collision at the interface between the matrix and the reinforcement materials, noting that the material behavior was similar with both ratios wt% [17].



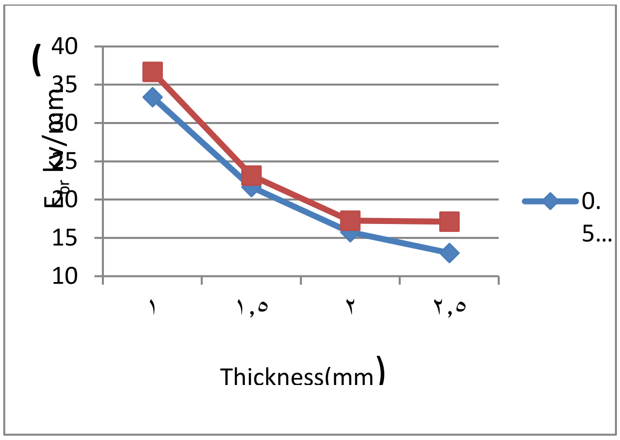


Fig.3: Variation of E_{br} wlth thickness for different (ZrO_2-Y_2O_3) additives a.1.5 Wt %, b.4.5 Wt%

The results also showed a decrease in the dielectric strength (E_{br}) with the number of breakdown cycles,(shown in Fig.4), due to the structural changes of the composite material and the decrease in its electrical resistance. This means that measuring the electrical breakdown of insulation materials is subject to statistical behavior, and this effect was more pronounced with the higher thickness of 1.5mm because of the electrothermal effects [10, 18].

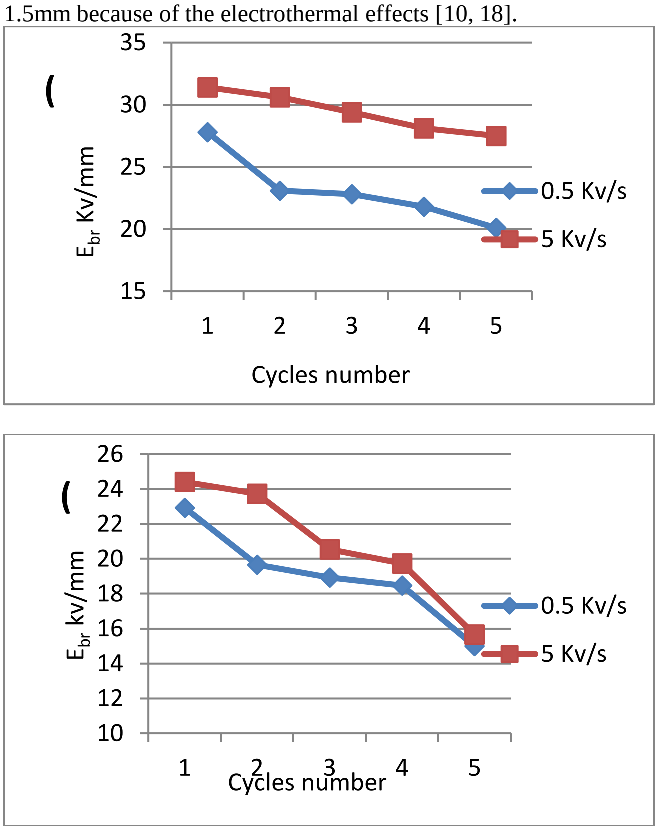


Fig. 4: Variation of E_{br} with Cycles number without immersion for 1.5 wt% (a.1mm, b.1.5mm) thickness.

After immersing composite material samples in the distilled water and diluted HCl and NaOH solutions, it had reduced the dielectric strength and this increase with the rise of the low voltages and the length of immersion time (Figs. 5 & 6) noticing that the effect of NaOH and HCL solutions is larger than distilled water and this means that the effect of water on the structure of the composite material {specifically the matrix material,(the polymer)} is less than the effect of the chemical solutions [10,19].

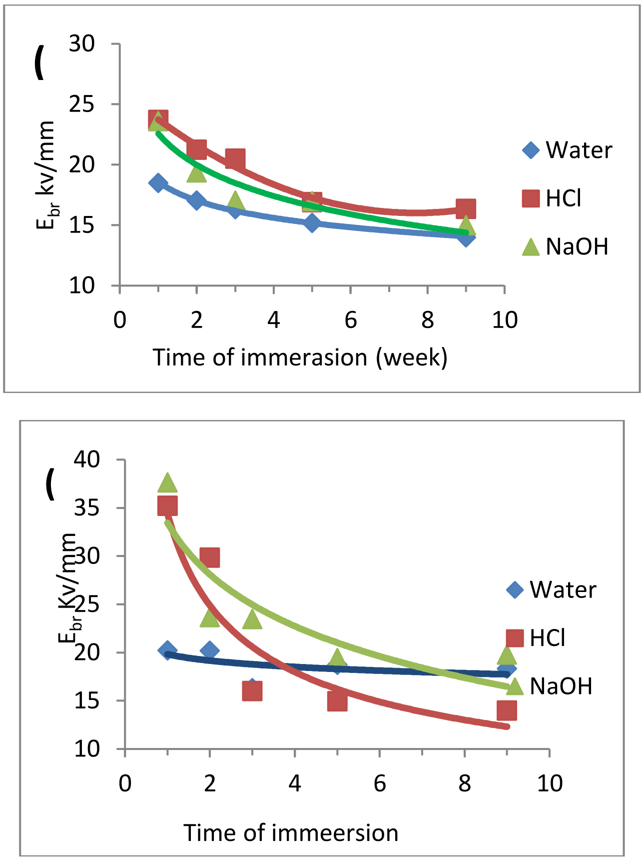


Fig .5: Variation of E_{br} with time of immersion with different solutions for 1.5 wt (ZrO_2-Y_2O_3) additive (a.for o.5 kv/s , b.for 5kv/s).

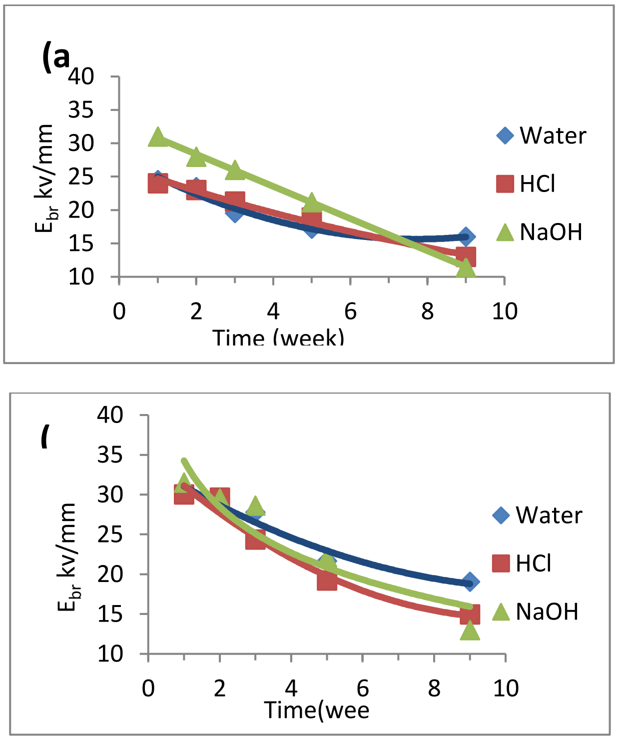


Fig .6: Variation of E_{br} with time of Immersion with different solutions for 4.5 wt% (a.for 0.5 kv/s , b. for 5 kv/s)

4.Conclusions

1- ZrO_2-Y_2O_3 (YSZ) particles work on dispersing the electric field within the composite material, and therefore increase the dielectric strength (E_{br}) .
2- The dielectric strength (E_{br}) is affected by the sample thickness and nonlinearly. Therefore, (E_{br}) increases in units of Kv/mm, whenever the thickness of the material is smaller.
3- The chemical solutions vary in the degree of impact on the dielectric strength (E_{br}) , whether it was acidic, base, or neutral, which differ in their degree of impact on the structural formation of the composite.
4- The effect of distilled water and chemical solutions will continue to decrease the dielectric strength (E_{br}) with the length time of immersion.

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