Journal of Engineering and Applied Sciences 13 (2): 484-488, 2018
ISSN: 1816-949X

Study of Factors Affecting the Dielectric Strength of [EP/Z_rO_2-y_2O_3] Nanocomposites

Ahmad H.M. Alfalahi
Department of Physics, College of Education for Pure Sciences, University of Anbar, Ramadi, Iraq

Abstract: A nanocomposite material was prepared from epoxy resin reinforced by nanoceramic powder [Nano Zirconia-Yttria (Z_rO_2-y_2O_3) (70-80 nm)] 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, 2.5 mm). The effect of addition rate (wt.%) was studied as well as 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 as well as 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 4.5 wt.% at the average of voltage increase 0.5 kV/sec) (and from 31.4 kV/mm for a ratio of 1.5 wt.% to 36.7 kV/mm for a ratio of 4.5 wt.% at the average of voltage increase of 5 kV/sec)] 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.

Key words: Epoxy resin, Zircon-Yttria, nanocomposite, dielectric strength, breakdown voltage, water

INTRODUCTION

Polymeric composite materials are the most important materials that meet the requirements of technological and industrial developments because of 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 these 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 material such as nanoparticles, two dimensional material such as nanofibers and one dimensional material such as nanoclays (Han and Fina, 2011; Zhao, 2013).

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 (Serway and Jewett, 2004).

Dielectric strength: Dielectric strength is defined as the ability of an insulator material to resist the maximum voltage imposed on it for a long period of time without failure, the voltage at which failure occurs is defined as breakdown voltage (Kuffel *et al*., 2000). The failure of an insulator is defined as 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}) (Yoon *et al*., 2009) whereby applying high electric field on the insulator 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 indictor (E_{br}) which is the filed at which the insulator material fails) (Mehta, 2004). According to Eq. 1:

$$E_{br} = V_{br}/t \text{ (kV/mm)} \tag{1}$$

Where:
V_{br} = The maximum applied voltage
t = The 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 by increasing the time of the voltages as shown in Fig. 1 (Kuffel *et al*., 2000; Pattouras *et al*., 2013).

Dielectric strength depends on many factors such as crystalline structure, defects and impurities found in the

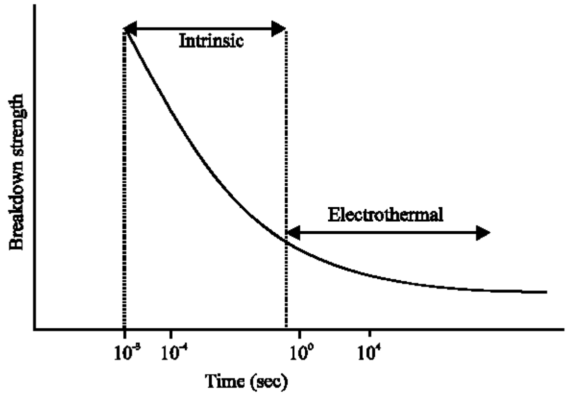

Fig. 1: Variation of electrical breakdown with time of applied voltage

insulator material, number of electrons and external factors such as the shape of the electrodes used to shed the electrical voltage, the 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 the number of cycles and thickness of the sample. There are two main types of electrical breakdown in insulators: intrinsic breakdown and electrothermal breakdown (Bunget and Popescu, 1984; Pampuch, 1976; Vouyovitch *et al*., 2006).

When an alternating voltage is applied to 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 the 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 due to the low resistance of the insulator material (Glushko *et al*., 2016).

Intrinsic breakdown: It is the collapse caused by the effect of the electric field when the voltage exerted on the insulator affects it for a very short period ($\approx 10^{-8}$ sec), hence, the so-called intrinsic field strength is created with the absence of other external influences as the intrinsic breakdown does not depend on the shape and dimensions of the sample and the nature and engineering of electrodes and it (E_{br}) 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 (Wu *et al*., 2004).

Electrothermal breakdown: When an effective voltage is applied to the insulator it releases heat from the insulator as a result 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 (Bunget and Popescu, 1984; Kroschwitz, 1988).

MATERIALS AND METHODS

Experimental procedures: An epoxy resins (type Polyprime EP) was used 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) (ZrO_2-Y_2O_3)] with particle size (70-80 nm) was 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 with 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 surfaces of the sample until the breakdown of the insulator occurs and using a low voltage rise rate 0.5 kV/sec and high 5 kV/sec for 5 cycles and by studying the effect of the ratio of addition and thickness and rate of rise of voltages and the number of cycles on the dielectric strength before immersion and then after immersion in distilled water and NaOH and HCL diluted solutions (0.5 N) to observe the effects of mentioned solutions on the insulation strength. The dielectrical strength for the samples was calculated according to Eq. 1.

RESULTS AND DISCUSSION

Before immersing, the results showed that (E_{br}) increased by increasing the ratio of (Z_rO_2-y_2, O_3) added to the polymer, Fig. 2 due to increased bonding between the matrix material and the reinforcement material 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 (Tuncer *et al*., 2007;

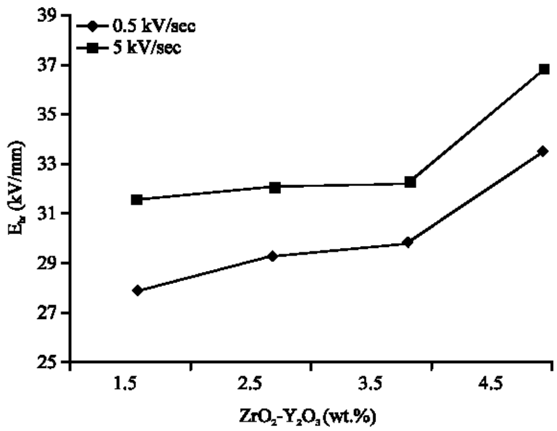

Fig. 2: Variation of E_{br} with different wt.% additives

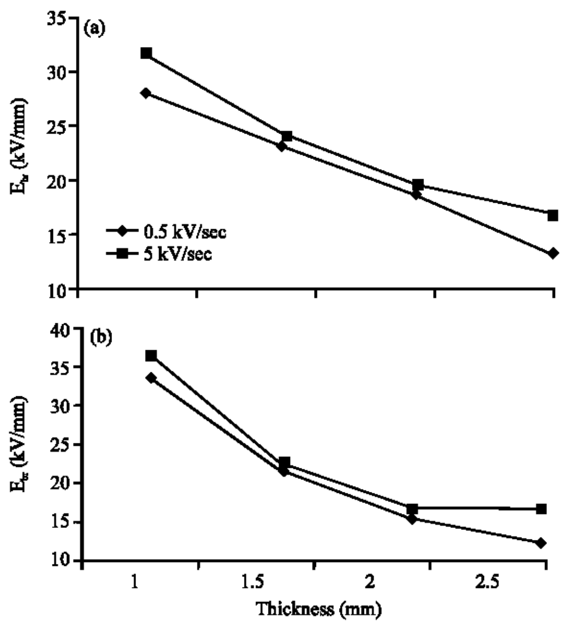

Fig. 3: Variation of E_{br} with thickness for different (ZrO_2.Y_2O_3) additives: a) 1.5 wt.% and b) 4.5 wt.%

Singha and Thomas, 2008). The higher the rate of voltages, the higher 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 due to leakage currents which leads to a decrease in the dielectric strength (Park, 2013).

Figure 3 shows that increasing the thickness of the sample led to a decrease in dielectric strength of the composite, the greatest amount of reduction in (E_{br}) was in the case of the low applied voltage (0.5 kV/sec), noting

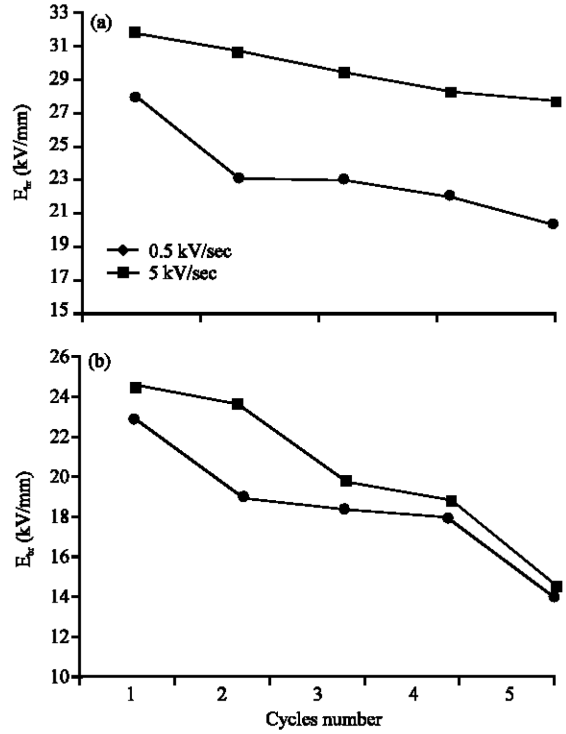

Fig. 4: Variation of E_{br} with cycles number without immersion for 1.5 wt.%: a) 1 mm and b) 1.5 mm) thickness

that the increase rate in the breakdown voltage was not proportional to the increase in the thickness of the material. On the other hand, increasing the 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 material and the reinforcement material, noting that the material behavior was similar with both ratios wt.% (Theodosiou *et al*., 2004).

The results of the tests also showed a decrease in the dielectric strength (E_{br}) with the number of breakdown cycles, 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 1.5 mm due to the electrothermal effects (Vouyovitch *et al*., 2006; Wu *et al*., 2004).

After immersing in the distilled water and the diluted HCl and NaOH solutions, it reduced the dielectric strength and this increases with the rise of the low voltages and the length of immersion time (Fig. 5 and 6) noticing that the effect of NaOH and HCL solutions is larger than distilled water and this means that the effect of

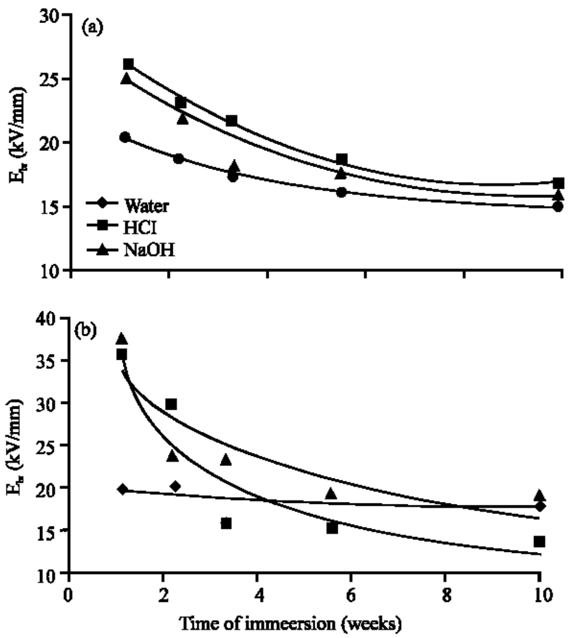

Fig. 5: Variation of E_{br} with time of immersion with different solutions for 1.5 wt. ($ZrO_2.Y_2O_3$) additive: a) For 0.5 kV/sec and b) for 5 kV/sec)

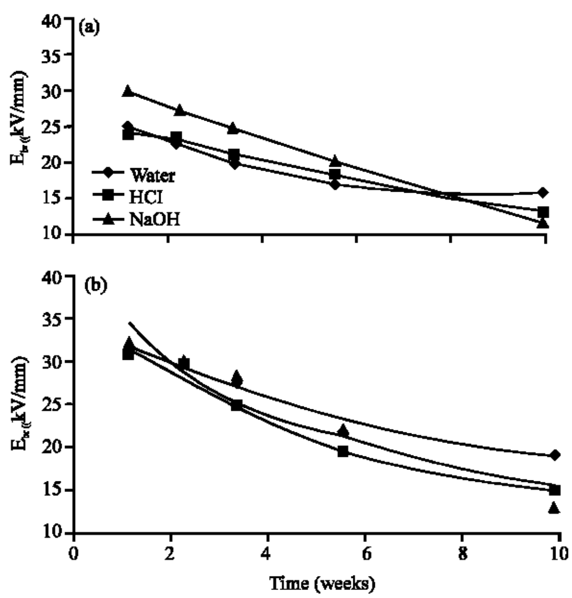

Fig. 6: Variation of E_{br} with time of Immersion with different solutions for 4.5 wt.%: a) For 0.5 kV/sec and b) For 5 kV/sec)

water on the structure of the composite material {specifically the matrix material (the polymer)} is less than the chemical solutions (Vouyovitch *et al.*, 2006; Dutta, 2008).

CONCLUSION

$ZrO_2.Y_2O_3$(YSZ) particles work on dispersing the electric field within the composite material and therefore increase the dielectric strength (E_{br}). The dielectric strength (E_{br}) is affected by the thickness of the sample and nonlinearly. Therefore, (E_{br}) increases in units of kV/mm whenever the thickness of the material is smaller. 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. The effect of distilled water and chemical solutions will continue to decrease the dielectric strength (E_{br}) with the length time of immersion.

ACKNOWLEDGEMENTS

Researchers would like to thank the division of materials science in the Department of Applied Sciences, University of Technology for their assistance in conducting tests of this research and would like to thank Dr. Shihab A. Zedan and Mr. Jaafar Karim and Mr. Duraid Mohammad for their assistance in completing this study.

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