Effect of Pyrex Waste on the Electrical and Mechanical Properties of an Epoxy Resin

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Abstract

In this study, Pyrex powder filler was added to an epoxy matrix in different weight ratios (0, 15, 30, and 45 wt.%) to study the electrical properties (real and imaginary dielectric constants, loss factor, and electrical conductivity) and the hardness test . The electrical properties were studied using a frequency range from 50 Hz to 1MHz at room temperature. The dielectric constant decreases with increasing frequency and increases with the Pyrex filler weight ratio. The loss factor (tan δ) and imaginary dielectric constant decrease with increasing frequency and increase with the weight ratio of the Pyrex filler, while the electrical conductivity decreases with increasing frequency. While the hardness value decreases with increasing Pyrex waste powder .

Key Wards: Pyrex, Hardness, Dielectric, Loss Factor, Epoxy

Introduction:

Epoxies, and thermosetting epoxies in particular, are commonly used in many applications. Thermosetting epoxy resins possess special characteristics, such as a compact structure and nonvolatile formation during curing. The curing temperature, as well as the degree of crosslinking, can easily be controlled. Also it is inherently brittle nature and ability to fracture because of a low toughness in addition to their poor resistance to crack propagation and low impact strength. These properties are considered to be their main disadvantages [1]. To avoid these disadvantages and enhance material characteristics, a number of reinforcements may be added to epoxies, such as glass fibers [2], silica powder, and/or aramid fibers [3]. The type of added filler may largely depend upon the specific type of application for the epoxy. Composite materials can also provide various filler options for epoxies. Unfortunately, the number of studies regarding the types of fillers that can be used, the effect of each type of reinforcement filler, and the suitability of different types of fillers for each application remains too limited to provide a useful database that could supply engineers with the features of each filler type to assist in the selection process [4].

Pure polymers are normally electrical insulators, and while insulating polymers may have very small concentrations of free charge carriers, they remain nonconductive and translucent to electromagnetic radioactivity [5]. Such polymers may possess chemical properties similar to those of other molecules, this means that a range of factors, such as stress cracking and dispersion of chemical additives, can change the molecular construction and hence the essential properties of the polymers [6]. Several changes, such as an unintentional decrease in the molecular weight, can lead to plastic degradation and produce failure, although other changes can improve the polymer characteristics [7]. Epoxies are one of the most essential thermoset polymers. Because of their corrosion resistance, desired chemical properties, good mechanical properties and low thermal conductivity, epoxies have been widely used in numerous fields as coverings, high-performance pastes and composite matrices, to name a few [8].

Many studies have investigated the addition of non polymeric fillers to improve the physical properties of polymers. Muhammad Akram et al., studied prepared the composite materials from polyester with different types of glass fiber at the temperature range (25-150)^{o}and frequency (330 H_Z-3MH_Z) the results showed increase the real dielectric constant and dielectric loss with addition glass fiber and decrease the dielectric loss with frequency .[9]. Jassim M. Salman studied effect of carbon black powder on the mechanical and physical properties for the unsaturated polyester by the different ratio (5, 7.5, 10) % wt the results show increased tensile strength values in the ratio 10% of carbon black powder and hardness increase in 7% with carbon black. Also impact and flexural strength improve compared with pure unsaturated polyester by 22% and 20% . [10]. The studies by Walaa revealed the frequency effect of the dielectric properties due to the addition of different weight ratios of copper (Cu) to an epoxy resin. In this study, both the real and imaginary dielectric constants increased with the Cu weight ratio and decreased with increasing frequency [11]. In the studies Kemal Y. and Qzer Taga thermal and electrical conductivity of composite material from unsaturated polyester resin with copper powder from the results shoe increase both electrical and thermal conductivity increase when increase the copper powder and with increasing powder partical size. [12].

The aim of this study is to determine the electrical properties (real and imaginary dielectric constants, loss factor and electrical conductivity) plus the mechanical properties, including the hardness, of a composite material consisting of an epoxy resin reinforced by Pyrex waste powder.

Experimental Procedures

Materials:

The matrix material used in the present study was an epoxy (Quickmast 105) consisting of two units for the preparation of the epoxy resin fluid. The amine hardener was supplied by Fosroc (Jordan), where the requisite resin-to-hardener ratio was 5:3. The reinforcement material was waste Pyrex, which is a type of hard glass used in the laboratory glassware industry. The Pyrex was washed, dried in an oven and ground in a porcelain mill. A grain size of less than or equal to 25 µm was achieved using a sieve (25 µm mesh).

Preparation Method:

The Pyrex waste was added to the epoxy resin in amounts of 0, 15, 30, and 45 wt.% and mixed for 3 min with a mechanical mixer. When a homogeneous mixture was obtained, the hardener was added in a ratio of 5 : 3, and the material was mixed manually with a glass rod for one minute. The mixture was then poured into a mold with a diameter of 2 cm and a thickness of 12 cm. The sample was hardened for 24 h and then placed in an oven for one hour at 50°C to complete the hardening process.

Electrical properties

The test included the dielectric constant, loss tangent (tan δ) and the imaginary dielectric constant at 10 mV with an applied frequency range of 50 Hz to 1 MHz, as determined using an LCR meter (Rs-232, Taiwan, LCR-8000G). The AC drive signal level (20 Hz to 5 MHz) (0.01 V to 2 Vrms). The dielectric constant, loss tangent and the imaginary dielectric constant were calculated by using the following equation [13]:

$$\acute{\varepsilon}= d.c /A\ \varepsilon_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where έ is the dielectric constant, d is the thickness of the sample, and c is the capacitance.

Additionally:

$$\tan\delta = \H{\varepsilon}/\acute{\varepsilon} \ \rightarrow \H{\varepsilon}=\tan\delta\ \acute{\varepsilon}\ldots\ldots\ldots\ldots\ldots(2)$$

Where ε̋ is the imaginary dielectric constant. Note that the values of tan δ were taken from the LCR meter.

For insulating materials, we could study the effects of the temperature and the filler addition on the electrical resistivity of the polymer composite by using a three-electrode cell or the guard-ring electrode method, and the resistivity (ρ) value (in Ω.m) of the composite was calculated from equation [14]:

$$\rho= R.A/L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where R is the resistance of the sample (Ω), A is the composite area (m^2), and L is the length (m).

Therefore, the conductivity (σ) was calculated by using the relation:

$$\sigma= 1/\rho \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4).$$

Hardness Test:

The hardness testing was performed with a Shore (D) Durometer (TH210, Italy). This test was performed according to ISO 9001 using the standard hardness value, which depends on the degree of penetration, that appears on the screen of the instrument.

Results and Discussion:

In Figs 1-3, which show the real and imaginary dielectric constants and the tangent factor as a function of frequency, show that decreases in the real and imaginary dielectric constants and the loss factor with the frequency. The dielectric constant is a frequency-dependent parameter with polymers. In the model, the epoxy resin structure is based on an epoxy cured with a hardener, and in the present case, the epoxy contribution to the dielectric constant is based on the quantity of oriented dipoles existing in the structure and their ability to orient in an electric field [15]. Typically, the molecules that are attached vertically to a longitudinal polymer chain add to the dielectric constant. At a low frequency and for a given voltage, the dipolar groups in the epoxy chain can orient themselves and increase the dielectric constant. In addition, as the electric field increases, the large dipole groups have difficulty in orienting with respect to the dipolar groups, which decreases the dielectric constant [16]. Show that that the real and imaginary dielectric constants and the loss tangent increase with the weight ratio of Pyrex waste due to interfacial polarization. When the materials are placed in an electric field, the charged particles interact with the field. Figs 4-5 show the variations in the real dielectric constant for both high and low frequencies. The real dielectric constant increases with the weight ratio of Pyrex waste in the high-frequency regime (50 Hz); however, in the low-frequency regime (1 MHz), the increase is random with respect to the weight ratio [17].

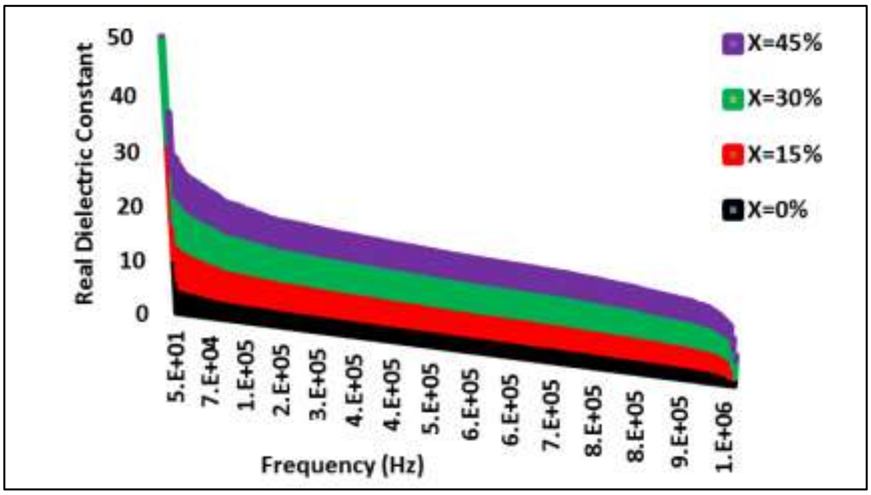

Figure (1). The real dielectric constant as a function of the frequency.

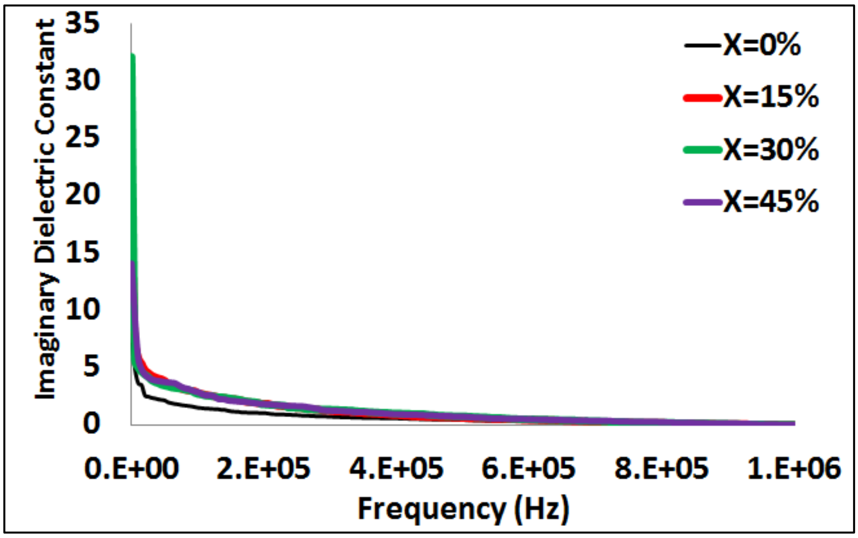

Figure (2). The imaginary dielectric constant as a function of the frequency.

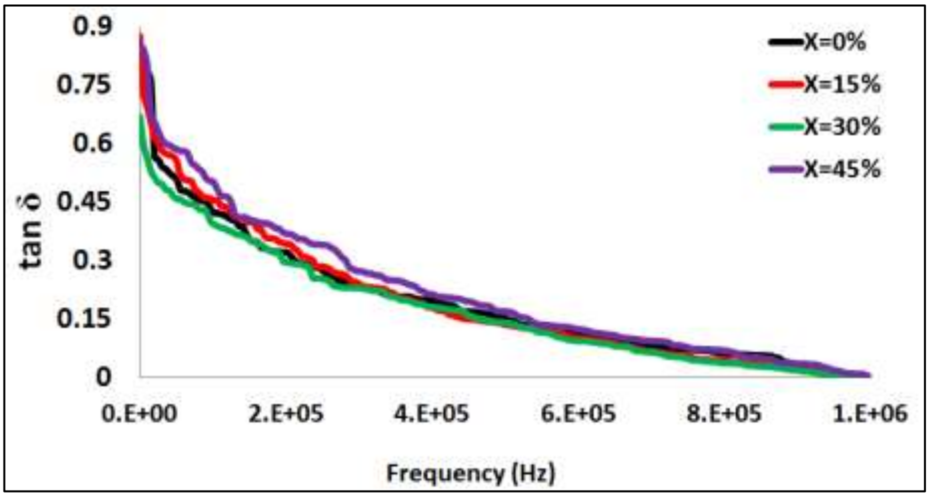

Figure (3). The loss tangent factor as a function of the frequency.

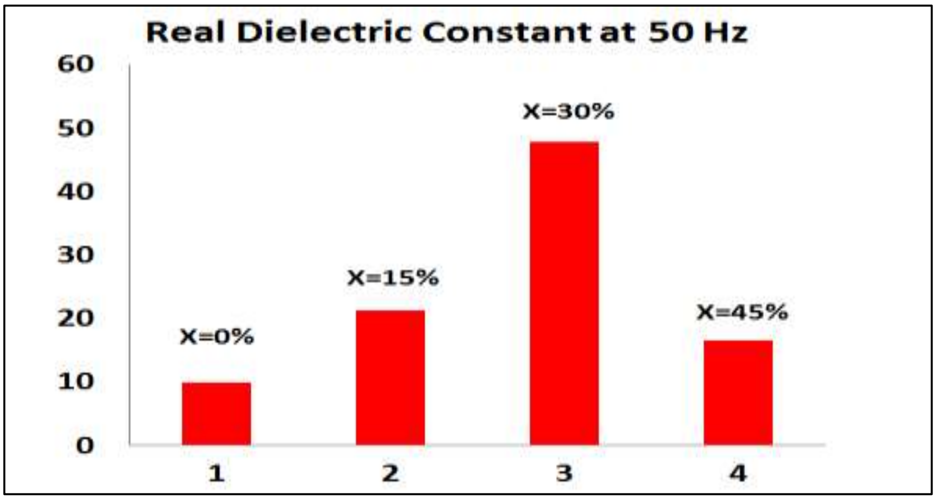

Figure (4). The real dielectric constant at 50 Hz and the weight ratio of Pyrex waste.

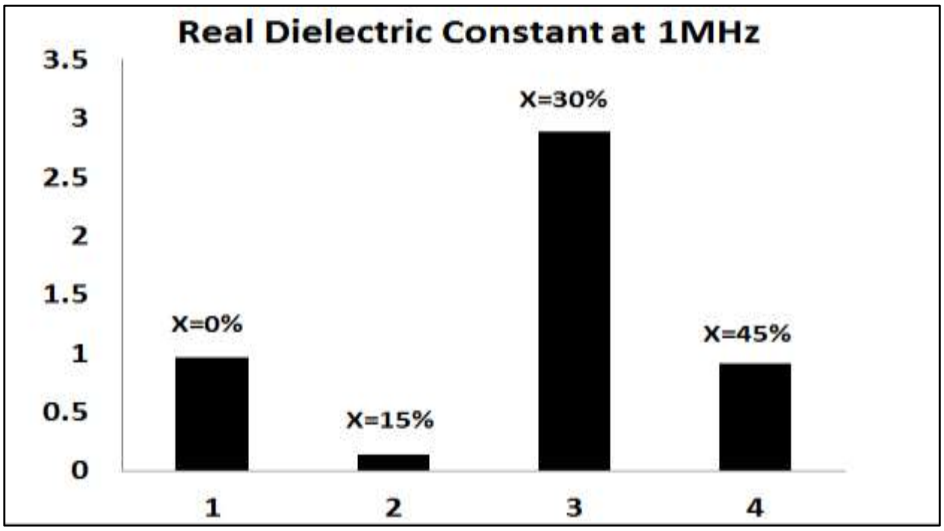

Figure (5). The real dielectric constant at 1 MHz and the weight ratio of Pyrex waste.

Fig (6) shows the value of lnσ as a function of the frequency, and we can see a decrease in the electrical conductivity as the frequency is increased. In the same figure, we observe a decrease in the electrical conductivity with an increase in the

Pyrex waste weight ratio. This decrease is attributed to the Pyrex glass exhibiting poor electrical properties as an excellent insulator. Figure (6). The relation between lnσ and frequency

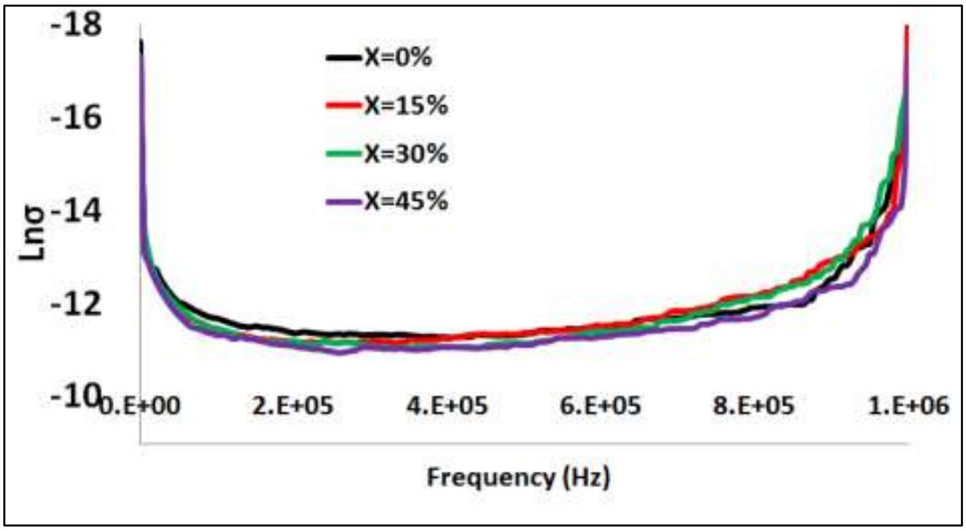

Fig (6) shows the value of lnσ as a function of the frequency

Fig (7) shows the relation between the hardness and the Pyrex waste weight ratio. This figure reveals a decrease in the hardness with an increase in the weight ratio because the interfacial adhesion between the matrix and filler is low. In addition, the filler elements cannot reduce crack propagation. Therefore, a catastrophic crack can spread and decrease the hardness of the composite. Meanwhile, as the number of filler agglomerates increases, the interfacial adhesion decreases, leading to weak interfacial regions. These agglomerates concentrate the introduced stress at the filler material and thus increase the overall hardness [18].

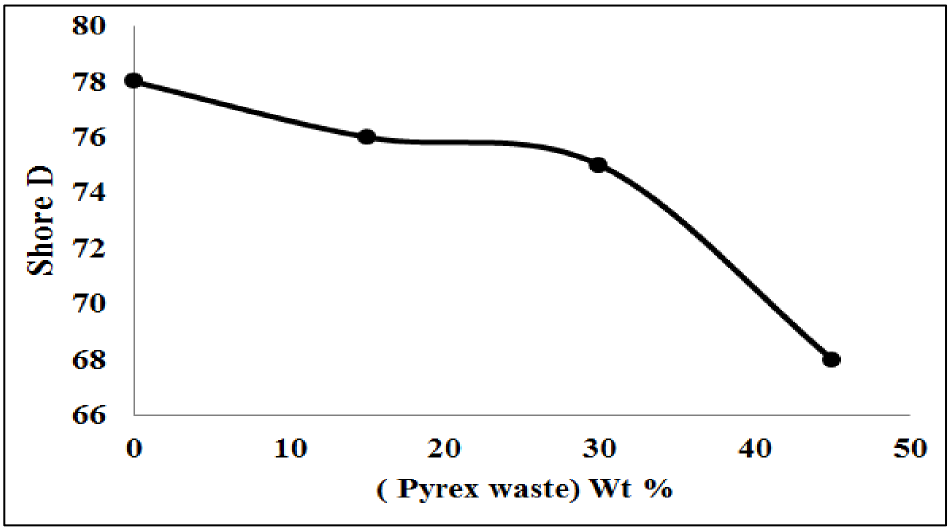

Figure (7). The relation between the hardness and the weight ratio of Pyrex waste.

Fig (8) provides optical micrographs of the morphologies of the epoxy and composite material with different percentages of Pyrex waste filler. Clearly, the optimum amount (30%) provided improved miscibility between the polymer and filler.

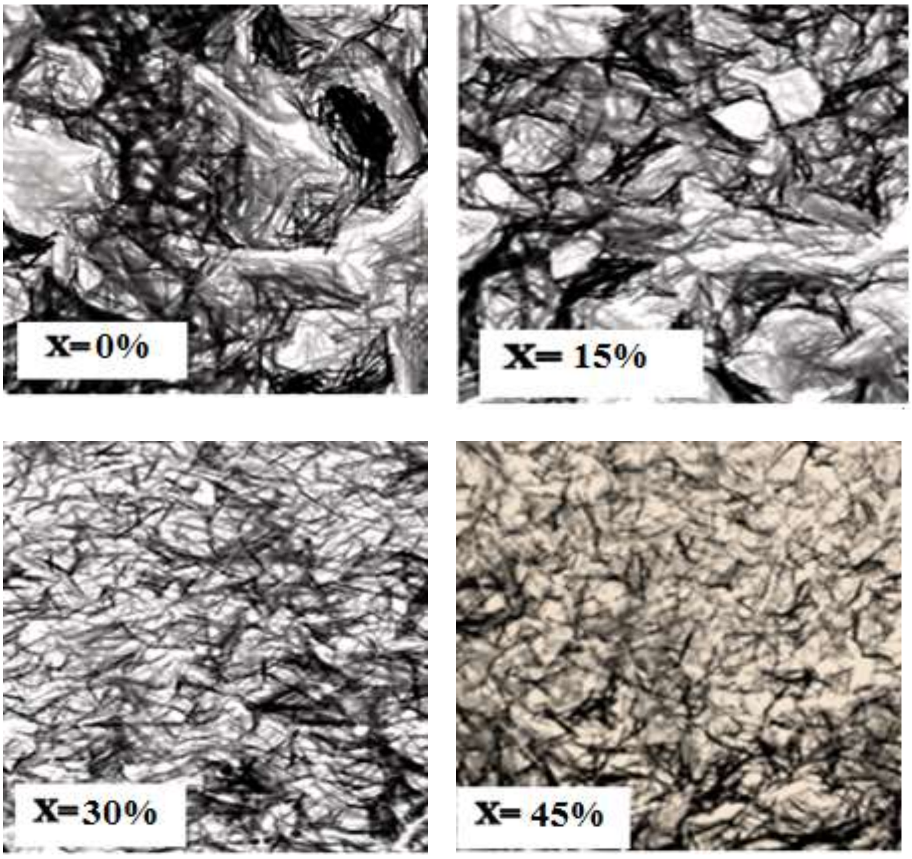

Figure (8). Optical micrographs of the morphologies of the epoxy and composite material with different percentages of (Pyrex waste) filler.

Conclusion:

In conclusion, the real and imaginary dielectric constants and tangent loss factor decrease with increasing frequency. However, the real and imaginary dielectric constants increase with the Pyrex waste weight ratio. The electrical conductivity decreases as the frequency increases and increases with the weight ratio. The composite hardness decreases as the Pyrex waste weight ratio increases.

References:

1- Hodgkin, J.H., Simon, G. P., and Valery, R. J , (1998) , "Thermoplastic Toughening of Epoxy Resins: a Critical Review", Polymers for Advanced Technologies, Volume 9, Issue 1, J.Wiley online library.

2-Chakrapa Tuakta, (2005), "Use of Fiber Reinforced Polymer Composites in Bridge Structure", Master of Engineering in Civil and Environmental Engineering at the Massachusetts Institute of Technology, USA

3-Akbar Afghi-Khatibia, and Yiu-Wing Maib, (2002), "Characterization of fiber/matrix Interfacial degradation under cyclic fatigue loading using dynamic mechanical analysis", Composites: Part A 33, 1585 – 1592 , Elsevier Science Ltd.

4-Zinah Abdulateef Abbas, Suad H. Aleabi Studying Some of Mechanical Properties (Tensile, Impact , Hardness) and Thermal conductivity of polymer blend reinforce by magnesium oxide " : AIP Conference Proceedings 2123, 020036 (2019).

5- Ye X, Yang Y, Tang G (2014) Micro hardness and corrosion behavior of surfa ce gradient oxide coating on the titanium alloy strips under high energy electro pulsing treatment. Surface and Coatings Technology 258: 467-484Ye X, Liu T, Ye Y (2015)

6- Ye, X., Liu, T., Ye, Y., Wang, H., Tang, G., & Song, G. (2018). Retraction notice to" Enhanced grain refinement and microhardness of Ti–Al–V alloy by electropulsing ultrasonic shock"[Journal of Alloys and Compounds 621 (2015) 66–70]. Journal of Alloys and Compounds, 769, 1146

7- Dhal JP, Mishra SC (2013) Investigation of Dielectric Properties of a Novel Hybrid Polymer Composite using Industrial and Bio-waste. Journal of Polymer Composites 1: 22-27.

8- Abbas RA (2007) Studying Some Dielectric Properties and Effective Parameters of Composite Materials Containing of Novolak Resin. Journal of Engineering and Technology 25: 277-28

9- Muhammed Akram, Athar Javed, Tasneem Zahra Rizvi, (Dielectric Properties of Industrial Polymer Composite Materials) Turk J Phys, 29. pp (355-362) , 2005.

10- Jassim Mohammed Salman, (Studying Some Properties of Unsaturated Polyester Composite Reinforced by Carbon Black Particulate), Journal of Babylon University / Engeineering Science / No. 2, Vol. 23, (2015).

11- Walaa W.Jameel" Studying the effect of frequency on dielectric properties of Cu powder reinforced epoxy composite material", Nahrain University ,college of engineering journal (NUCEJ), Vol.17,No.1, 2014.109-113.

12- Kemal Yaman and Qzer Tga ,(Thermal and Electrical Conductivity of Unsaturated Polyester Resin Filled with Copper Filler Composite),International Journal of Polymer Science , Vol. 2018 , Article ID 8190190.10 pages.

13-- A. Monshi, M. R. Foroughi and M. R. Monshi, (2012). "Modified Scherer Equation to Estimate More Accurately Nano-Crystallite Size Using XRD". World Journal of Nano Science and Engineering, 2: 154-160.

14-- Murthy BSR, Dr.A. Rama Krishna and B.V. Rama Krishna, "Thermal Analysis of Epoxy Based Fiber Reinforced", IE(I) Journal – MC, Vol.84, April, (2004).

15-Starke TKH, Johnston C, Hill S, Dobson P, Grant PS (2006) The effect of In homogeneities in particle distribution on the dielectric properties of composite films. Journal of Physics D: Applied Physics 39: 1305-1311

16-Calame JP (2006) Finite difference simulations of permittivity and electric field statistics in ceramic-polymer composites for capacitor applications. Journal of Applied Physics 99: 084101.

17- Shatha H.Mahdi, Qasem Abd Saloom, Duna Sami Abd A laziz "Preparation of unsaturated polyester/nano ceramic composite and study electric, thermal and mechanical properties", Iraqi Journal of Physics , vol. 15, No. 35, pp 188-201, (2017).

18- Ramakrishna H. V. and S. K Rai "Utilization of Granite Powder as a Filler for Polybutylene Terepthalate Toughened Epoxy Resin" Journal of Minerals & Materials Characterization (2006). &Engineering, Vol. 5, No.1, pp. 1-19