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& Scientific Research
University of Diyala
College of Sciences
Department of Physics*



Studying The Dielectric Properties of (Polymer – Ceramic) Composite

A Thesis

Submitted to The Council of the College of Sciences, University
of Diyala in Partial Fulfillment of the Requirements for the
Degree of Master of sciences in Physics

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1433هـ

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

أَلَمْ تَرَ أَنَّ اللَّهَ أَنْزَلَ مِنَ السَّمَاءِ مَاءً
فَأَخْرَجْنَا بِهِ ثَمَرَاتٍ مُخْتَلِفًا أَلْوَانُهَا وَمِنَ
الْجِبَالِ جُدُدٌ بَيْضٌ وَحُمْرٌ مُخْتَلِفٌ أَلْوَانُهَا
وَعَرَابِيبٌ سُودٌ ﴿٢٧﴾ وَمِنَ النَّاسِ وَالدَّوَابِّ
وَالْأَنْعَامِ مُخْتَلِفٌ أَلْوَانُهُ كَذَلِكَ إِنَّمَا يَخْشَى
اللَّهَ مِنْ عِبَادِهِ الْعُلَمَاءُ إِنَّ اللَّهَ عَزِيزٌ غَفُورٌ ﴿٢٨﴾

صَلِّ عَلَى اللَّهِ الْعَظِيمِ

سورة فاطر

الاية {27-28}

DEDICATION

To the three pillars of my life: my God, my father and my mother. Without you, my life would fall apart. I might not know where the life's road will take me, but Walking with You:

My God, through this journey has given me Strength.

My Mother, you have given me so much, thanks for your faith in me, and for teaching me that I should never surrender.

My Father, you always told me to “reach for the stars.” I think I got my first one.

Thanks for inspiring. We made it...

Omar

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Abstract

This research investigates the effect of adding ceramic materials which represent aluminum dioxide (Alumina- Al_2O_3) and titanium dioxide (Titania- TiO_2), with different particle sizes ranging between micro size (30 μm) and nano size (30 nm) as dispersion to Unsaturated Polyester (UP) as a matrix material and also the studying of some affecting factors on the dielectric strength, dielectric constant, dispersion factor (loss tangent), and X-ray examination of the composite material. Reinforcement ceramic materials (Alumina and Titania) with weight fraction (1%, 2%, 3%, 4%) was added to Unsaturated Polyester, and prepared by Hand lay-Up Molding with the thicknesses ranged between (1-4) mm. Generally, the results of tests have shown the decrease of dielectric strength with increase in proportion of additive ceramic, and the values of dielectric strength of the composite (UP + TiO_2) was less than the values of dielectric strength of the composite (UP + Al_2O_3) This is due to the high dielectric constant possession for titanium dioxide, with dielectric loss factor higher than alumina compared with other insulator materials and also it appear that the dielectric strength decreases with increasing dielectric loss factor.

The results showed for both Composites (UP + Al_2O_3) and (UP + TiO_2) respectively, a decreasing in the dielectric strength with thickness increasing, and increasing in the dielectric strength with the increases of the voltage elevating average. The effect of the number of breakdowns on the dielectric strength of both composites has decreased clearly after the first round. The results have shown for both Composites (UP + Al_2O_3) and (UP + TiO_2), respectively, It was also shown the increase in the values of dielectric constant with increasing of the proportion of additive ceramic (Alumina + Titania) and a decrease in the values of dielectric constant with increasing frequency. Tangent loss was observed that its value increases with increasing frequency reach to the highest value at the relaxation frequency and then its values start to decrease

gradually at frequencies greater than relaxation frequency. The x-ray examinations clear for both Composites (UP + Al₂O₃) and (UP + TiO₂) in the electric breakdown region didn't occur any changes in the phases for the constituent materials of the sample, and there is no new material has been appear after the test. 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 (UP) destroyed, and there is appearance of micro cracks as a result of electric breakdown extends directly from the point of electric breakdown.

CONTENTS

Subject	Page
Chapter One: Introduction & Previous Studies	
1-1 Introduction	1
1-2 Previous Studies	3
1-3 Aims of the Study	8
Chapter Two: Theoretical Background	
2-1 Composite Materials	9
2-2 Classification of Composites Materials	10
2-3 Polymer Matrix Composites (PMC)	10
2-4 Resins	12
2.4.1 Thermoplastic Resins	12
2.4.2 Thermosetting Resins	13
2.5 Polyester Resins	13
2.6 Properties & Application of Polyester	14
2.7 Polyester Resin Types	15
2.8 Particulate Reinforcing	16
2.8.1 Particulate Strengthening	17
2.8.2 Dispersion Strengthening	17
2.9 Reinforcement materials	18
2.9.1 Alumina	18
2.9.2 Titania	20
2-10 Nanocomposite	21
2-11 The electrical properties of nanocomposite	22
2.12 Dielectrics	23
2.13 Classification of Dielectric	25

2.14 polarization	26
2.15 Types of Polarization	28
2.15.1 Electronic Polarization	28
2.15.2 Ionic Polarization	28
2.15.3 Orientation Polarization	28
2.15.4 Interfacial Polarization	28
2.16 Dielectric Properties	30
2.16.1 Dielectric constant	30
2.16.2 Dielectric loss	31
2.16.3 Dielectric strength	34
2.17 Main Types of Breakdown That Occur In Insulators	37
2.17.1 Intrinsic Breakdown	37
2.17.2 Electrothermal Breakdown	38
2.17.3 Electromechanical breakdown	40
2.17.4 Streamer Breakdown	41
2.17.5 Erosion Breakdown	44
2.18 Factors affecting on the Dielectric Strength	46
Chapter Three: Experimental Part	
3.1 Introduction	51
3.2 The Materials Used	53
3.2.1 Matrix Material	53
3.2.2 Reinforced Materials	55
3.3 Molding preparation	58
3.4 Preparation of Specimens	59
3.5 Instrumentations	61
3.6 Electric Tests	64
3.6.1 Dielectric strength	64

3.6.2 Dielectric constant	65
3.6.3 Dispersion factor (Tangent loss)	65
Chapter Four: Results & Discussion	
4.1 Introduction	66
4.2 Dielectric Strength	66
4.2.1 Effect of thickness	66
4.2.2 Average Elevating Voltage	70
4.2.3 The Effect of The Number of breakdowns	76
4.3 Examination by x-ray diffraction	82
4.4 Optical Microscope Pictures	84
4.5 The Effect of Additives rates on The Dielectric Constant	87
4-6 The Effect of Frequency on The Dielectric Constant	90
4-7 The Effect of frequency on the dispersion factor	92
Chapter Five: Conclusions & Recommendations	
5.1 Conclusions	99
5.2 Recommendations	100
References	

LIST OF TABLES

No.	Title	Page
(2-1)	Main category of the types of insulators at 20°C temperature.	25
(3-1)	The characteristics of (UP) by the manufacturer specifications.	54
(3-2)	Electric Characteristics of (UP).	54
(3-3)	Specifications of micro alumina by the manufacturer.	55
(3-4)	Specifications of nano alumina by the manufacturer.	56
(3-5)	Specifications of micro Titania by the manufacturer.	57
(3-6)	Specifications of nano Titania by the manufacturer.	58

LIST OF FIGURES

No.	Title	Page
(2-1)	Classification Scheme of Various Composite Types.	10
(2-2)	Sketch energy Bands In The Absolute Zero temp. for insulators.	23
(2-3)	Schematic diagram for the types of Polarization.	29
(2-4)	Show simplified diagram of currents in a loss dielectric.	32
(2-5)	Shows The Relationship Between Current And Voltage In The Solid Insulators.	36
(2-6)	Mechanisms of Failure and Variation of Breakdown Strength in Solids with Time of Stressing.	37
(2-7)	draw to function ($\phi(\beta h)$), And the(x-axis) logarithmic.	39
(2-8)	Breakdown of Solid Specimen due to Ambient Discharge-Edge Effect.	42
(2-9)	Breakdown channels in plexiglass between point-plane electrodes.	44
(2-10)	Electrical discharge in cavity and its equivalent circuit.	45
(2-11)	Sequence of cavity breakdown under alternating voltages.	46
(2-12)	Effect of thickness on the dielectric strength.	48
(2-13)	Effect of temperature on dielectric strength.	49
(3-1)	Technological Process Steps Used In The Current Research	52
(3-2)	XRD pattern for the micro gamma alumina powder.	55
(3-3)	XRD pattern for the nano alpha alumina powder.	56
(3-4)	XRD pattern for the micro titania powder.	57
(3-5)	XRD pattern for the nano titania powder.	58
(3-6)	Dielectric Strength Instrument.	62
(3-7)	LCR Meter.	63
(3-8)	Optical microscope.	63

(4-1)	Dielectric strength versus thickness (UP).	68
(4-2)	Dielectric strength versus thickness (UP+1% MA).	68
(4-3)	Dielectric strength versus thickness (UP+4% MA).	69
(4-4)	Dielectric strength versus thickness (UP+1% NA).	69
(4-5)	Dielectric strength versus thickness (UP+4% NA).	70
(4-6)	Dielectric strength versus average elevating voltage(UP).	71
(4-7)	Dielectric strength versus average elevating voltage (UP+1% MA).	72
(4-8)	Dielectric strength versus average elevating voltage (UP+4% MA).	72
(4-9)	Dielectric strength versus average elevating voltage (UP+1% NA).	73
(4-10)	Dielectric strength versus average elevating voltage (UP+4% NA).	73
(4-11)	Dielectric strength versus average elevating voltage (UP+1% MT).	74
(4-12)	Dielectric strength versus average elevating voltage (UP+4% MT).	74
(4-13)	Dielectric strength versus average elevating voltage (UP+1% MT).	75
(4-14)	dielectric strength versus average elevating voltage (UP+4% NT).	75
(4-15)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec),(UP).	77
(4-16)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1%MA)	77
(4-17)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4%MA)	78
(4-18)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% NA)	78
(4-19)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% NA).	79
(4-20)	dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% MT)	79
(4-21)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% MT)	80
(4-22)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% NT)	80

(4-23)	Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% NT)	82
(4-24)	XRD pattern for the (UP+4%NA) before the electric breakdown.	82
(4-25)	XRD pattern for the (UP+4%NA) after the electric breakdown.	83
(4-26)	XRD pattern for the (UP+4%NT) before the electric breakdown.	83
(4-27)	XRD pattern for the (UP+4%NT) after the electric breakdown.	84
(4-28)	Sample before breakdown (UP).	85
(4-29)	Sample after breakdown (UP).	85
(4-30)	Sample after breakdown (UP+1%MA).	85
(4-31)	Sample after breakdown (UP+1%MA).	85
(4-32)	Sample after breakdown (UP+1%MA).	85
(4-33)	Sample after breakdown (UP+2%MA).	85
(4-34)	Sample after breakdown (UP+3%MA).	86
(4-35)	Sample after breakdown (UP+4%MA).	86
(4-36)	Sample after breakdown(UP+1%NA).	86
(4-37)	Sample after breakdown (UP+1%NA).	86
(4-38)	Sample after breakdown (UP+2%MA).	86
(4-39)	Sample after breakdown (UP+3%MA).	86
(4-40)	Sample after breakdown (UP+4%NA).	87
(4-41)	Sample after breakdown (UP+4%NA).	87
(4-42)	Dielectric constant versus weight fraction at (5×10^6 Hz), (for all additives).	89
(4-43)	Dielectric constant versus weight fraction at (25049.75 Hz),(for all additives).	89
(4-44)	Dielectric constant versus frequency for alumina additives.	91
(4-45)	Dielectric constant versus frequency for titania additives.	91
(4-46)	Dielectric constant versus frequency for all additives.	92
(4-47)	Tangent loss versus frequency (UP).	94

(4-48)	Tangent loss versus frequency (UP+1%MA).	95
(4-49)	Tangent loss versus frequency (Up+4%MA).	95
(4-50)	Tangent loss versus frequency (UP+1% NA).	96
(4-51)	Tangent loss versus frequency (UP+4% NA).	96
(4-52)	Tangent loss versus frequency (UP+1%MT).	97
(4-53)	Tangent loss versus frequency (UP+4%MT).	97
(4-54)	Tangent loss versus frequency (UP+1% NT).	98
(4-55)	Tangent loss versus frequency (UP+4% NT).	98

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition	Unit
f	Frequency	Hz
P	Polarization	C/m^2
q	Electric charge	C
N	Number of dipoles per unit volume	$1/m^3$
d	Separated distance	mm
D	Electric displacement	C/m^2
E	Electric field	V/cm
ϵ_0	Permittivity of Vacuum (8.85×10^{-12})	F/m
ϵ_r	Relative permittivity (Dielectric Constant)	---
C_0	Vacuum capacitance	F
C	Capacitance of dielectric material	F
ϵ	Permittivity of the dielectric material	F/m
P_ω	Loss power	W
V	Voltage	V
R	Resistance	Ω
I	Current	A
X_c	Impedance of capacitor	Ω
ω	Angular frequency ($2\pi f$)	$rad.s^{-1}$
j	Imaginary route, $\sqrt{-1}$	---
ϕ	Phase angle	degree
δ	Loss angle	degree
I_a	Active current (resistive current)	A
I_r	Reactive current (capacitive current)	A
ϵ'_r	Real dielectric constant	---
ϵ''_r	Imaginary dielectric constant	---

$\tan\delta$	Tangent loss angle	---
Q	Quality factor	---
E_{br}	Dielectric field strength	kV/mm
V_{br}	Breakdown voltage	kV
h	Dielectric thickness	mm
λ	Coefficient of Thermal Conductivity	W/m.K
α	Thermal Coefficient of dielectric loses factor.	K^{-1}
h_l	Thickness of Pole	mm
Y	Young's modulus	Gpa
R.T	Room temperature	$^{\circ}C$
UP	Unsaturated Polyester	---
MA	Micro Alumina	---
NA	Nano Alumina	---
MT	Micro Titania	---
NT	Nano Titania	---
XRD	X-Ray Diffraction	---

CERTIFICATION

We certify that this thesis has been prepared under our supervision at the University of Diyala / College of Sciences / Department of Physics as a partial fulfillment of the requirements for the Degree of Master of sciences in Physics.

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In view of the available recommendation, I forward this thesis for debate by the examining committee.

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Date: / / 2012

Examination Committee Certificate

We certify, that we have read the thesis title (*studying the dielectric properties of (polymer-ceramic) composite*), presented by (*Omar Ahmad Hussein Al-jubouri*) and as an examining committee, we examined the student on its contents, and in what is related to it, and that in our opinion it meets the standard of a thesis for the degree of master in Physics Sciences with an () degree.

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Chapter One



**Introduction
and
Previous Studies**

Chapter Two



**Theoretical
Background**

Chapter Three



Experimental Part

Chapter Four



**Results
and
Discussion**

Chapter Five



**Conclusions
and
Recommendations**

References



ACCEPTED RESEARCHES FOR PUBLISHED

1-I participated in third Scientific conference – College of Sciences – University of Diyala by research (A study effect of thickness and number of Breakdowns on the Dielectric Strength of (Polyester – Nanoceramic) Composite), which occurred in (6 -7/5/2012) and the research accepted in Diyala University journal for pure Sciences.

2-I participated in Seminar about (The Role of Universities and Scientific research in Industry Development of Glasses, Ceramic and Refractories in Iraq), which occurred in University of Technology in (10/5/2012).

الخلاصة

يتضمن هذا البحث دراسة تأثير إضافة مواد سيراميكية والمتمثلة بثنائي أكسيد الألمنيوم (الألومينا - Al_2O_3) وثنائي أكسيد التيتانيوم (التيتانيا - TiO_2) وبأحجام دقائق مختلفة تتراوح بين الحجم المايكروي والحجم النانوي كمادة مدعمة لمادة البولي استر غير المشبع (UP - Unsaturated polyester) ودراسة بعض العوامل المؤثرة على متانة العزل الكهربائي وثابت العزل الكهربائي وظل الفقد والفحص بالأشعة السينية للمادة المترابكة. أضيفت المواد السيراميكية المدعمة (الألومينا و التيتانيا) بنسب وزنيه هي (1%، 2%، 3%، 4%) للبولي استر غير المشبع، وحضرت النماذج بطريقة القوالب اليدوية (Hand lay- Up Molding) وبأسماك تراوحت بين (1- 4) ملم. أظهرت نتائج الفحوصات على العموم تناقص في متانة العزل الكهربائي مع زيادة نسبة السيراميك المضاف، وأن قيم متانة العزل الكهربائي للمترابك (UP + TiO_2) كانت اقل من قيم متانة العزل الكهربائي للمترابك (UP + Al_2O_3) وهذا يعزى إلى امتلاك ثنائي أكسيد التيتانيوم ثابت عزل كهربائي عالي، ومعامل فقدان عزلي أعلى من الألومينا مقارنة مع المواد العازلة الأخرى وان متانة العزل تتناقص مع زيادة معامل الفقدان العزلي.

بينت النتائج لكلا المترابكين (UP + Al_2O_3) و (UP + TiO_2) تناقصاً في متانة العزل مع زيادة السمك وزيادة متانة العزل الكهربائي مع زيادة المعدل الزمني لصعود الفولتية. أما تأثير عدد الدورات على متانة العزل الكهربائي لكلا المترابكين فقد تناقصت متانة العزل الكهربائي بشكل واضح بعد الدورة الأولى. وقد بينت النتائج لكلا المترابكين (UP + Al_2O_3) و (UP + TiO_2) تزايداً في قيم ثابت العزل الكهربائي مع زيادة نسبة السيراميك المضاف وتناقصاً في قيم ثابت العزل الكهربائي مع زيادة التردد. أما ظل الفقد فلو حظ بأن قيمته تزداد مع زيادة الترددات لتصل إلى أعلى قيمة لها عند تردد الاسترخاء، ثم تبدأ بعد ذلك قيمته بالانخفاض تدريجياً عند الترددات الأكبر من تردد الاسترخاء. أما فحوصات الأشعة السينية لكلا المترابكين (UP + Al_2O_3) و (UP + TiO_2) فقد وضحت على العموم في المنطقة التي يحدث فيها انهياراً كهربائياً لا تغيير في الأطوار بالنسبة للمواد المكونة للعينة وعدم ظهور مواد جديدة بعد الاختبار.

أما الصور المأخوذة لمنطقة الانهيار باستعمال المجهر الضوئي فقد بينت تفحم النموذج في منطقة الانهيار نتيجة تحطم السلاسل البوليمرية لبوليمر البولي الاستر غير المشبع (UP)، وحصول شقوق مجهرية نتيجة الانهيار تمتد مباشرة من نقطة الانهيار.

1.1 Introduction

Because of the possession of composite materials of some properties that suit many industrial applications, they gained a prominent place among different engineering materials, where the composite materials combine the properties of two or more exceeding disadvantages of each material. In addition to that, they have the ability to control their properties, either by the type and proportions of constituent materials, or through its design and methods of manufacture[1]. Therefore, the designers and engineers focus at the present time on the effective role of engineering materials that have entered into various industrial fields, so it has been selected, produced by multiple processes and consecutive according to the structure design and construction fit with functionality as well as the analysis of failure in requested performance [1,2].

In response to the requirements of development industrial progress and walking towards improving the performance of the product in terms of design and manufacturing, there are efforts to form composite materials that have strength, durability and reliability in terms of its beauty and resistance to erosion, while in the electric fields, we find there is a desire to produce integrated circuits, For example, the keys of the computer for instantaneous interaction, dielectric and endure the high voltage, while in the motor cars industry has been used materials with light weight and high durability. furthermore, Space fields are required materials with light weight and good performance in order to resist the weather conditions (temperature, for example) of outer space [2]. The Specialists noted in the field of materials science (such as metals, ceramics and polymers) difference in the characteristics, type of available materials, the general behavior, also the impact of environmental conditions and services in the functionality performance of the materials [3].

In this work, The researcher used the polymers which are inert materials, light weight and generally has a high degree of ductile, which is characterized by lower electrical conductivity and thermal so used as insulators electrical and thermal. when compared with the metals they are low density, large elongation

when there is a change in temperature, low stiffness, high resistance to corrosion and they do not consider hardened materials [4]. Ceramics materials are inorganic and non-metal [3], such as oxides, carbides, Nitrides and others, where ceramic materials tend to be poor connectivity, electric and thermal, this is means insulating material characterized by brittle resulting from decrease of ductile and thus lower resistance to shocks, but it has the hardness and compression strength and chemically lethargic, Thus ceramic is not used in applications under the effect of impact loads compared to metals, however, it is resistant to high temperatures [2,4].

The composite materials that have polymer matrix of the oldest composite materials[1]. and consist of the first phase which is known Matrix material and be of ductile material with high durability, such as polymers, while the second phase is called Reinforcement phase which may be in the form of (fibers, or particles, or flakes) of solid material such as (polymers, ceramics, metals) [4].

Recently, a large window of opportunity has been opened to overcome the limitations of traditional micrometer-scale polymer composites and nanoscale filled polymer composites in which the filler is <100 nm in at least one dimension [5].

The science in direction nanofillers is called Nanoscience and nanotechnology that pertain to the synthesis, characterization, exploitation and utilization of nanostructured materials which are characterized by at least one dimension in the nanometer ($1 \text{ nm} = 10^{-9} \text{ m}$) range. Such nanostructured systems constitute a bridge between single molecules and infinite bulk systems. Individual nanostructures involve clusters, nanoparticles, nanocrystals, quantum dots, nanowires and nanotubes, while collections of nanostructures involve arrays, assemblies and super lattices of individual nanostructures. The dimensional range of 1 to 100 nm is referred as the nanoscale and materials at this scale are called nanocrystals or nanomaterials. The chemical and physical properties of nanomaterials can significantly differ from those of bulk materials of same

chemical composition. The uniqueness of the structural characteristics, energetics, response, dynamics and chemistry of nanostructures constitutes the experimental and conceptual background for the field of nanoscience. Suitable control of properties and response of nanostructures can lead to new devices and technologies[6]. The origin of the size-induced properties in nanomaterials depends basically on the surface phenomena (extrinsic contribution) and quantum confinement effects (intrinsic contribution).

Polymer composites are important commercial materials with applications that include filled elastomers for damping, electrical insulators, thermal conductors, and high-performance composites for use in aircraft, and from important applications as nanoscale sensors, electronic and optical nanodevices [5].

1.2 Previous Studies

1. Z.- M. Dang, et., al. (2003) [7], have studied the dielectric behavior of novel three-phase multi-walled carbon nanotubes (MWNTs),(BaTiO₃), polyvinylidene Fluoride (PVDF) composites and found a novel three-phase percolative composite with conductive MWNTs and ferroelectric particles (BaTiO₃) embedded into the PVDF matrix. The three-phase composite has a high dielectric constant ($\epsilon_r=450$) and good flexibility. The dielectric measurement results show that the effective dielectric constant of the composite is slightly dependent on the frequency below (1 MHz) but increases rapidly with the MWNTs concentration when the concentration is very close to the percolation threshold. The temperature has a little effect on the variation of the dielectric behavior. the dependence of the dielectric constant and electrical conductivity of the composites on frequency.

2. Qunqiang Feng, et., al., (2003) [8], have studied preparation and dielectric property of Ag/PVA nanocomposite. The composite with (20-30) nm Ag particles has a higher resistivity and breakdown field than its matrix. Coulomb blockade effects of metal powders could improve resistivity and breakdown

field of its matrix. The breakdown field of polymer films in which Ag nano particles were added, was about double that of the sample without Ag nano particles. The metal nano particles which were dispersed uniformly in the insulating matrix can make electron get across one by one, blocking the charge carrier of the whole system to move directionally by the action of electric field. Therefore, such effects improve the breakdown field strength of the composites. For the composite films, the resistivity can be raised to ten times bigger than the pure PVA, and the breakdown field strength can be raised to three times bigger. And at cryogenic temperature, the resistance rate of composite can be raised even more.

3. Vishal Singh, et., al., (2003) [9], have studied dielectric properties of Al-Epoxy composites were characterized as a function of composition and frequency. The dielectric constant increased smoothly with an increase in the concentration of aluminum. An increase in dielectric constant was also observed with a decrease in frequency. In general, dissipation factor values for composites with higher concentrations of aluminum were greater than those with lower volume content of aluminum. Also, the dissipation factor showed an increase with a decrease in frequency.

4. Rola, (2007) [10], has studied the Dielectric constant and dielectric strength of composite materials that consist of Novolak reinforced with glass fiber, Novolak reinforced with asbestos fiber and Novolak reinforced with (60%) ratio of glass fiber and asbestos have been studied. The specimens were made in different ratios of Hexamethylenetetramine (HMTA) content of (10%) and (14%), Then a study was carried out on the influence of (HMTA) on dielectric constant and dielectric strength of these specimens. It was found that permittivity and dielectric strength for composite materials are dependent matrix the types and properties of reinforcing materials. Then the relation between dielectric constant and frequency and temperature and percentage moisture

absorption was studied. It was found that dielectric constant increases when the temperature and percent-age moisture absorption increase, whereas dielectric constant is dependent on capacity of composite materials.

5. Al-ammam, (2008) [11], has studied the most important effect of factors on the dielectric strength of (ceramic-glass)composites which are produced of Alumina (Al_2O_3)and Magnesia (MgO) as matrix and soda lime glass as supported material. He found that the dielectric strength decreased by adding mount of glass, thickness and high temperature for all samples, also with lower average to rise voltage. He found that the composites produced of Alumina cannot use it in practical applications after first period loading of breakdown.

6. Al-Zubaidy, (2009) [12], has studied the effect of adding not burn and burn Kaolin supported by (PVC) as matrix. She found a decrease in dielectric strength with the amount of Kaolin for both composites and the values of dielectric strength for composite (PVC-not burn Kaolin) lower than dielectric strength for composite to (PVC-burn Kaolin). Also, the dielectric strength decreased with increasing in thickness, temperature and number of breakdowns. Dielectric strength increased with average time of voltage evaluated for both composites.

7. Eduard A. Stefanescu, et., al., (2010) [13], have studied the influence of calcium copper titanate (CCTO), and montmorillonite (MMT) on the thermo-mechanical and dielectric properties of poly(methyl methacrylate)PMMA-based composites. MMT was used for its ability to disperse and suspend the CCTO particles through the generation of viscous monomer slurries. The filler addition was found to improve the thermal stability and the glass transition temperature of PMMA in the composites. Furthermore, the elastic stiffness and dielectric constant of the resultant composites were observed to increase monotonically

with filler loading. By contrast, the dielectric breakdown strength of the composite samples was found to diminish with increasing filler loading.

8. Samer, (2010) [14], has studied the influence of electromechanical for different types of glass. He studied the effect of electric breakdown on bending strength and some factors effecting on bending strength and dielectric strength for soda lime glass and Pyrex after heat treat. The dielectric strength was decreased when the thickness and the periodic loading of breakdown increased. Soda lime glass and Pyrex samples show increased in dielectric strength with increase in rise voltage average. the optical microscope pictures show electric breakdown and cracks on samples.

9. Bahaa, (2011) [15], has studied Electrical Properties of (poly-methyl methacry- late-Alumina) (PMMA - Al_2O_3) Composites. the PMMA samples with Al_2O_3 additive prepared with different percentages(0,15,25,35 and 45) wt.% . He found that The dielectric constant decreasing with the frequency and increase with Al_2O_3 wt.% content. The dielectric loss is oscillatory in the whole frequency region and increase with increasing Al_2O_3 wt.% content. The D.C electrical conductivity of the poly-methyl methacrylate increases by increasing the Al_2O_3 concentrations and the temperature. The A.C electrical conductivity of PMMA - Al_2O_3 composites is increasing with increasing frequency of applied electrical field and Al_2O_3 wt. % content.

10. V. Tome, et, al., (2011) [16], have studied Polyethylene nanocomposite dielectrics (polyethylene (PE)) as a matrix and clay and silicate as fillers, to enhance the dielectric properties of thermoplastic polymers, when the mitigation of internal charges and the nature of the interfacial regions are properly adjusted. In particular, it is shown that filler alignment can be used to improve the high electric-field breakdown strength and the recoverable energy density. Further, it is conclusively demonstrated that the alignment of the two-dimensional

nanoparticles has a measurable positive effect on the breakdown strength of the materials and, consequently, on the maximum recoverable energy density. Experimentally observed dielectric breakdown strengths, plotted as a probability of failure versus applied electric dc field (Weibull statistics). The Weibull fitted lines and the corresponding parameters are also found for a pure (unfilled) polymer, for a nanocomposite with random fillers, and for a nanocomposite with oriented fillers. There is a strong effect of the filler orientation on the breakdown behavior of the composites, which results in marked improvement of the high field breakdown strength for the oriented filler nanocomposites.

11. Chia-Ching Wu, t., al., (2011) [17], have studied $(\text{Ba}_{0.8}\text{Sr}_{0.2})(\text{Ti}_{0.9}\text{Zr}_{0.1})\text{O}_3$ (BSTZ) ceramic powder mixed with polyetherimide (PEI) to form flexible PEI/BSTZ composites, and the effects that different BSTZ content has on the dielectric properties of these composites are investigated. The dielectric constant increases from 2.52 to 20.28 as the BSTZ filler content increases from 0 wt% to 70 wt%.

12. Weimin Xia, et., al., (2012) [18], have studied the dielectric properties of poly(vinylidene fluoride-chlorotrifluoroethylene) (P(VDF-CTFE) and BaSrTiO_3 (BST) nanocomposites. The addition of BST nanoparticles could enhance the dielectric constant of the resultant composite significantly. The dielectric constant for all samples decrease as a function of frequency ranging from 100 Hz to 10 MHz. Furthermore, The dielectric constant increase continuously as more BST nanoparticles are introduced and reach 82 at 100Hz in composite with 30 wt% BST. In addition, dielectric loss was little at lower frequency, dielectric loss of nanocomposites increase as the contents of BST particles at low frequency.

13. Ram Avatar Sharma, et., al., (2012) [19], have studied the effect of nano and micro silica on 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. It may be due to interfacial bonding between the UPR and the silica particles. the value of the dielectric constant is slightly lower in the nano silica-UPR composite. This is due to the successful interaction between the polymer and the surface of the silica particles. The values of the dielectric constant keep decreasing till a loading 1.5 phr silica in UPR resin. after this, the values of the dielectric constant are almost the same. This may be due to the agglomeration of the silica particles in the UPR resin. the dissipation factor decreases up to the nano silica loading of 1.5 percentages and then, it becomes constant. It may be due to the reduction of the internal discharge by the interfacial region of the polymer matrix and the filler at filler concentration more than 1.5 percentages.

1.3 Aims of the Study

- 1.** preparing composites that consist of unsaturated polyester as the matrix material which reinforced by aluminum dioxide (Alumina) and titanium dioxide (Titania) with different particle sizes and different weight fraction, that distinguished by high dispersion.
- 2.** studying some affecting factors (thickness, average elevating voltage and number of breakdowns) on dielectric strength.
- 3.** Studying dielectric constant, loss tangent (dispersion factor), and the influence of the effecting factors (additives materials and frequency) on them.
- 4.** X-ray examination for the electric breakdown points to make sure of create a new materials or not which may caused by thermal effect of the voltage.

2.1 Composite Materials

The materials are described by the three traditional primary classifications they are: metals, ceramics, and polymers. There is an increasing emphasis on combining materials from these different categories, or even different materials within each category, in such a way as to achieve properties and performance that are unique. Such materials are called composites [20]. A composite material has been defined as: “A substance consisting of two or more materials, insoluble in one another, which are combined to form a useful engineering material possessing certain properties not possessed by the constituents” [21]. These materials are discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement material; whereas the continuous phase is termed the matrix, the matrix holds the reinforcements in an orderly pattern [22]. This work focuses on particle-reinforced composites composed of particles embedded in a matrix; The particles are in the range microsize and nanosize, and the matrix is polymer. Generally the composite materials consist of [23] :

A- Matrix Phase:

1. The primary phase, having a continuous character.
2. Usually more ductile and less hard phase.
3. Holds the reinforcing phase and shares a load with it.

B- Reinforcing Phase:

1. Second phase is imbedded in the matrix in a discontinuous form.
2. Usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

And Performance of Composite depends on:

1. Properties of matrix and reinforcement.
2. Size and distribution of constituents.
3. Shape of constituents and nature of interface between constituents.

2.2 Classification of Composites Materials

Some of the common classifications of composite materials are reinforcement-Based [22], that can be divided in to:

- Particle-reinforced.
- Fiber-reinforced.
- Structural, which contains Sandwich panels and Laminates as shown in, Figure (2.1). Basically, composites can be categorized into three groups on the basis of matrix material. They are: [24]

- Metal Matrix Composites (MMC).
- Ceramic Matrix Composites (CMC).
- Polymer Matrix Composites (PMC).

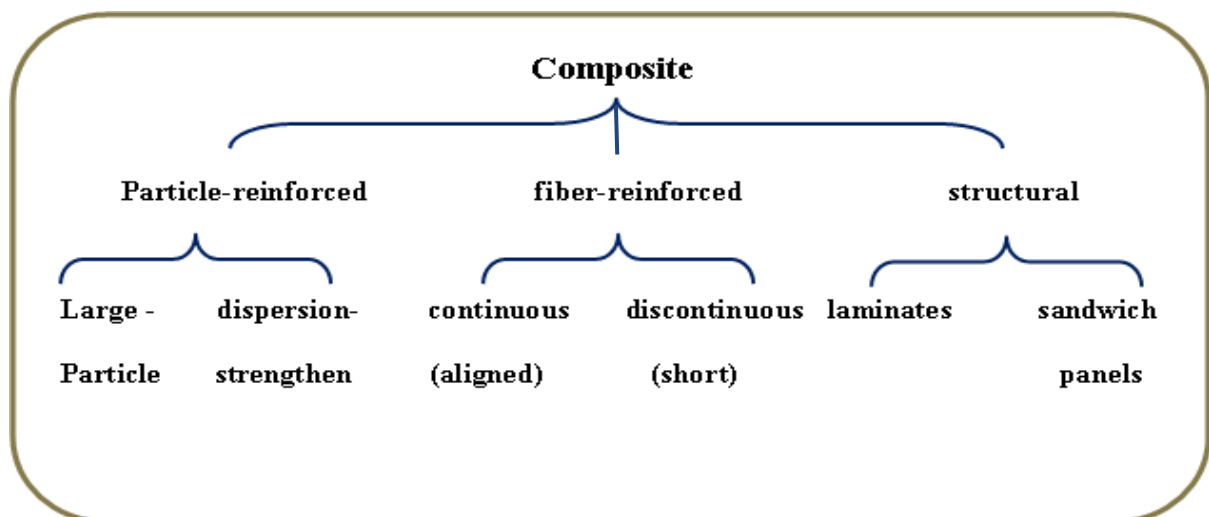


Fig. (2.1) Classification Scheme of Various Composite Types.[22]

2-3 Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polysterene) and embedded ceramic, glass, carbon, steel or Kevlar fibers (dispersed phase) [23,25]. These are the most commonly used matrix material. In general the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and

ceramics. These difficulties are overcome by reinforcing other Materials with polymers. The processing of this type of matrix composites do not require high pressure and high temperature. The equipments which are required for manufacturing polymer matrix composites are simpler. For this reason polymer composites developed rapidly and soon became popular for structural applications. Polymer composites are used because overall properties of these composites are superior to those of the individual polymers. The elastic modulus is greater than that of the neat polymer but are not as brittle as ceramics [24].

The polymer matrix composites have some required properties, we can note that the potential advantages of PMC are manifold:

- 1- Light weight.
- 2- High corrosion resistance.
- 3- Relative high flexibility of manufacture (large complex structure can be fabricated in one piece minimizing tooling costs and obviating the need for joints fastenings).
- 4- It is a tremendous scope for innovative design without the constraints of conventional metal forming or machining process.
- 5- Excellent thermal properties, it is possible to fabricate PMC with very low thermal expansively and thermal conductivity which may be significance in certain applications.
- 6- Electrical properties, certain PMC are excellent electrical insulators and also some of them are conducting and photo conducting materials.
- 7- High specific strength [26 - 28].

In terms of disadvantages two of them require particular attention [28] :

- a- Lack of ductility.
- b- The properties of certain PMC are dependent on direction.

There are three main types of PMC, classified according to the type of reinforcing materials, fibrous polymer matrix composites, particulate polymer

matrix composites, and non-filler polymer matrix composites. Generally the filler are divided into organic fillers such as polymeric and natural fibers (banana, jut, and sisal), compatibility agents, pigments and flame retardants, and inorganic fillers such as fibers (glass, carbon, basalt, boron) and metallic particulate fillers.

2.4 Resins

Because of the development witnessed the world in the field of polymeric materials has entered the resin in the composition of raw materials for the manufacture of polymers, which can be defined as a complex polymer composed of organic materials is amorphous (non crystalline) may be natural or industry consists of small particles called “monomer” and linked to a large numbers of these molecules chemically bonded to this set up polymeric chains arrange in non-crystalline (amorphous) when it hardening [29].

Resins are divided into two types: -

2.4.1 Thermoplastic Resins

Thermoplastic are polymeric Materials few branching and has a small reticulate Linking and can be converted easily into a paste plastic configuration easy or liquid as pressure and temperature that uses without any change in their chemical properties or chemical composition, and when cooled hardens easily and can be re-melted several times using the heat whichever can be recycled. This type of polymer changing in the shape by the impact of load which leads to the sliding chains of molecular on each other because of weak the bonds that connect them (Vander waals forces) such as polyethylene, poly vinyl chloride and polypropylene and thus become more ductility and formational easy [30,31].

These materials are sensitive to the temperature where it can become paste when exposed to heat and then hardens when cooled and these polymers "Semi-crystalline" and have a high molecular weight, degrees of heat

transmission different according to materials, the susceptibility of polymeric materials on the crystallization depends on the temperature and manufacturing conditions. Therefore, this materials can be crystalline or amorphous or "Semi crystalline" [32].

2.4.2 Thermosetting Resins

The materials that may be formed by heat with or without using the pressure and these materials are solid permanently and more fragility (brittle) of the previous type and can not be re-formed again by heat. Chemical change occurs in its composition when exposed to pressure and temperature where softening in the beginning and constantly exposed to heat will become hardened as a result of the process of polymerization, and the molecular chains bonds by very strong covalent bonds will increase both the brittle and stiffness. Its types include industrial (polyester and epoxy) and natural (wool and wood), [31,33] and when these materials exposed to high temperatures, the covalent bonds between the atoms in the molecular chains will be break and degrade, amorphous materials, have a large Cross Linking and do not possess the degree of heat transmission.

2.5 Polyester Resins

The polyester resins of the most polymeric materials using in the present time because of the low cost, characterization of high performance and operating at a fast rates. The polyester reactions of heat emitting reactions, so must overcome on this heat and control it during the configuration process, The high heat leads to the occurrence of cracks and fissures caused by generating heat stress in the final product and therefore this will affect on the mechanical properties, physical and electrical of these materials. The preparing of polyester of raw materials can be obtained from petroleum that resulting (polyester) from the interaction of Dicarboxylic with Dihydric Alcohol. The Terephthalic Acid of

the most acid used in the preparation of this material, and includes the changes in this interaction composition of several materials, produced, thus resins with different properties significantly, as the properties of physical and electrical quality of the most important features of the polyester as well as ease of hardening and using without a come up of gases or any by product, and characterized by their resistance to corrosion and high temperature when adding small amounts of chemical materials, as well as resistance to weather conditions such as ultraviolet rays. As well as progress, the evolution which took place on this material made possible the formation of products with various shapes, sizes and economic prices better than it is in time past. these resins does not favor their use alone because they are not strong and don't have high stiffness, but when combined with the reinforcement material within certain combinations will gain properties of a good make it suitable for use in different fields [34,35].

2.6 Properties & Application of Polyester

Polyester resins are characterized by having a lot of physical properties at room temperature where it has a pink color transparent, solid and with fixed dimensions after the process of forming, configuration easy, could be processed quickly and with the viscosity ranging from (500-1000) centipoises, time of hardened (converted to gel material) takes 20 minutes, the percentage of styrene in which the range of (32-40)% and the qualitative weight or Relative density (1.2) g/cm³, low cost, the percentage of shrinkage ranging between (5-8)% as a result the shoot water molecule during the interaction, high dielectric and it characterized high resistance to water and chemicals materials [34,36]. the polyester can be used in many industries such as Chips, movies and some types of electrical insulators because of the insulation and high electric stability, and enters in the manufacture of composite materials that used structures of the aircraft industry and lining sidewalks as well as polyester fibers used in the manufacture of carpets and fabric parachutes [35-39], as used in the manufacture

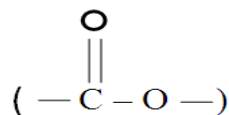
of fire hoses, ropes, fan blades and radio screens, helmets race car drivers and industry caravans[40,41], Also used for construction such as doors, windows, bridges and marine industries as well such as shipbuilding and fishing rods because of the low density, high tensile strength and high impact strength [42].

2.7 Polyester Resin Types

Polyester Resins can be divided into two types: -

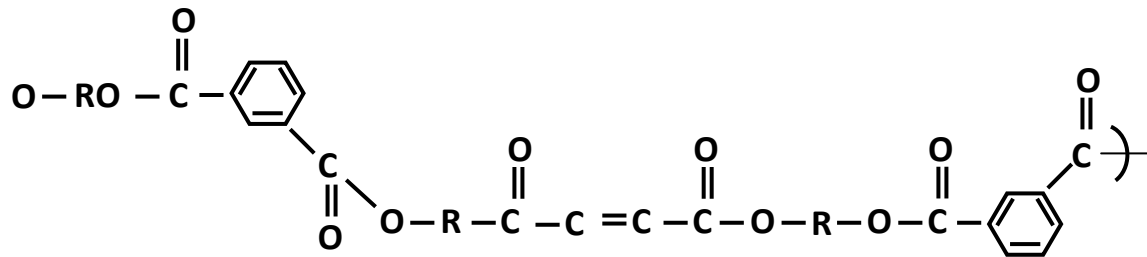
1- Saturated Polyester Resin are those materials prepared from the multiple monomers aggregates effective so that the cross linking process occurs during reactions of the multiple esters, and this type called “Saturated cross linking polyesters” and using in the manufacture of fibers and films.

2- Unsaturated Polyester Resin are those materials that are a process of cross linking by independent additional polymerization reaction Through active dual bonded in the main structure of the polyester is known of this type “unsaturated polyester resin”. It consists of chains of polymer dissolve in effective organic solvents by additions accelerators and assistance (catalysts) materials to the resin when it is in the liquid state, and operate accelerators to accelerate the reaction speed at room temperature and add this materials to occur chemical reaction without shedding any pressure then consists of compound of solid three-dimensional, can be defined unsaturated polyester resin as a industrial polymer in which the repeated components that forming molecular chains of the ester type and chemical formula are:-[43]



Unsaturated Polyester resin prepared of reaction its raw materials unsaturated dual carboxylic acid and saturated dual carboxylic acid (Terephthalic Acid) with a dual hydric alcohol (Ethylene Klykol) [44 - 46], and by removed water between the acid and the glycol, so the ester will be linked to

ring form and the result is to be a long series of molecules containing alternating units of acid and glycol as in the following chemical formula:-[43]



After completion of reaction and the addition of monomer or the dissolvent which represents the interference factor (cross link) (such as styrene) with the Inhibitor and all factors necessary for the purpose of forming and then cool the mixture at room temperature [42,43], and the change in the unsaturated activated of aggregates density in Polymeric chains be a significant effect on the resin and on the final characteristics, and important factors affecting the properties of the resin is the amount of content monomer, length of polymer chains and the amount of fillers [32,47].

2.8 Particulate Reinforcing

The particles are one of means of reinforcement to the matrix material where it is distributed in the matrix material randomly in order to obtain composite materials with good mechanical properties and symmetric[48], where the advantage of composite material that is reinforced by particles as having Equal Axial, in other words, the particles have same dimensions almost in all directions, and reinforcement materials in particles are classified in to metallic or nonmetallic into two main groups depending on the size of particles and on the reinforcement mechanical:[49]

2.8.1 Particulate Strengthening

Is one of the techniques used to strengthen the composite materials where the principle of work similar to the dispersion strengthening because they also work on deformities in the matrix material in addition to that they restrict the movement of matrix material in all directions and participates matrix material in carrying loads inflicted upon because of their large size [50], but they different from the dispersion strengthening in terms of particles size, so the particles size is larger than ($1\mu\text{m}$) and the volume fraction concentrations of more than (15%) of the material composite volume [50,51].

In the process of reinforcement the particles working as barriers to distort the matrix material because of the high hardness, non-distorted during loading. the particles consist of several types and forms including spherical, flake, needle and filamentous, where particles works to increase the hardness (Rigidity) of the material, Creep resistance, impact Resistance and improve of thermal expansion of the matrix material, it has been observed that this type of reinforcement includes the participation of particles with a matrix material in bearing stresses inflicted on the composite materials and the fracture occurs when exceeds the shear stress fracture resistance to reinforcement materials [52], and the amount of reinforcement depends on the strength of correlation between matrix material and particles[53], and the particles must be distributed uniformly (homogenous) within the matrix material, and the composite material particulate have Isotropic properties, and This is in itself a large useful in the applications that require similar properties, its examples, alumina particles and titania used in the current search.

2.8.2 Dispersion Strengthening

This method involves dispersing particles randomly within the matrix material where there is this kind of particles characterizes high solid, high thermal stability and non-soluble in matrix material, the mechanism of

reinforcement is the matrix material endure the largest part of shed stress on composite material while dispersion particles are working as barriers impede movement of dislocations formed in the matrix material during the process of plastic deformation and prevent the cracks, and the extent of strengthening depending on the effectiveness of dispersion particles on the impeded movement of dislocations, while the volume of particles used in this type of reinforcement is very soft, not to exceed (0.1 μm) and add the weight proportion of few ranging from (1-15%) and different volume fraction [54-57]. this method is cost due to the particles which used in its production have small particle size evaluate by nanometer (10^{-9}m)[53].

2.9 Reinforcement materials

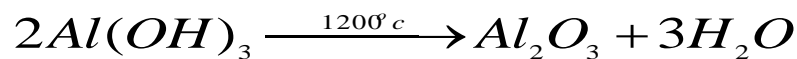
This is one of the basic components of Composite Materials where the added Reinforcement materials to the matrix material for the purpose of strengthening. This leads to enhance its properties and include the process of strengthening the transfer of load hanging from the matrix material to Reinforcement materials through the interface [58], these materials called of the secondary phase or the reinforcement phase or embedded phase [59]. reinforcement materials consist of several materials, including ceramic or metal or polymer are characterized in general as with high resistance, more stiffness from the matrix material and ductility ranges between high and low depending on the type of reinforcement material and the purpose that is used for, reinforcement materials classified depending on the shape and dimensions as Fibers, Particles and Flakes [60,61].

2.9.1 Alumina

This is (Al_2O_3), and it is called corundum (aluminum oxide crystalline) as an extra material in metamorphic rocks such as marble and igneous rocks, rich and poor aluminum such as cyanide, due to the hardness of the material and

not influence by the weather is often concentrated in the form of granules are carried in rivers streams and on the shores of the sea [62].

The bauxite (aluminum hydroxide) ($Al_2(OH)_6$) main raw material that we get alumina from it. As contain rate alumina (40-68) % as well as varying proportions of impurities (Fe_2O_3 , SiO_2 , TiO_2) that commonly used in multiple applications in ceramics and refractories [63-65]. Alumina prepares from bauxite heated by high temperature, as follows: -



Aluminum oxide (Al_2O_3), which is called alumina is a crystalline powder, white color, density (3.9 g/cm^3). Its melting point of ($2055 \pm 6^\circ C$), does not dissolve in water or acid and is used as itchy as it comes after the diamond in hardness. Furthermore, it is a good insulator of electricity. its energy gap (E.g.> 8eV) [66-68]. The dielectric strength (30kV/mm) if the purity (99.7%) and contain (MgO 0.5%), and (18kV/m) if the purity (97%) and contain silicate [69].

Alumina is one of the most widely used thermal oxides due to the high resistance to heat, mechanical durability and resistance to thermal shock [70]. and is used to form many articles such as spark plug cores, laser tubes, electrical insulators, thermocouple tubes, thread guides, valve seats, medical prosthesis, electronic substrates, grinding media, and many other products.[71] Mainly because of proliferation of preparative methods and the range of calcining temperature, many forms of alumina have been described. These mainly refer to partially dehydrated and improve forms that are basically ternary oxides. Pure alumina, $\alpha\text{-}Al_2O_3$, has a hexagonal close packed structure. Other forms such as $\beta\text{-}Al_2O_3$ and $\gamma\text{-}Al_2O_3$ precedes the α -form during calcinations of gibbsite. Generally, The typical characteristics of alumina include: good strength and stiffness, good hardness and wear resistance, good corrosion resistance, good thermal stability. Excellent dielectric properties, and law dielectric constant and loss tangent [72,73].

2.9.2 Titania

Titanium dioxide, or titania, which exist in three forms, namely: rutile (tetragonal), anatase (tetragonal) and brookite (orthorhombic). There are some differences in physical (e.g. crystal structure, stability, hardness, density) and optical (e.g. color, luster, brightness, refractive index) properties between them [74,75]. And Crude titanium dioxide, called titanium white [76-78].

The principal raw materials for manufacturing titanium dioxide include ilmenite (FeO/TiO_2), naturally occurring rutile, and titanium slag. The last is produced by removing the iron from Ilmenite by reduction with coke at (1200-1600°C). At these temperatures, the iron oxide is reduced to the metal, which melts and separates from the formed titanium-containing slag, which is (70-75%) titanium dioxide [74,75].

Rutile is the thermodynamically stable form at normal pressure and at all temperatures up to its melting point [79]. Whereas brookite and anatase are metastable and transformed to rutile on heating.(the transformation being exothermic) [77]. This transformation, achieved by increased temperature or pressure, concentration of lattice and surface defects, which mainly depend on the synthetic method and the presence of dopants and Particle size [80]. Titanium dioxide is insoluble in water, hydrochloric acid, dilute sulfuric acid, and organic solvents. It dissolves slowly in hydrofluoric acid and hot concentrated sulfuric acid. It is almost insoluble in aqueous alkaline media [74,75]. The commercial properties of TiO_2 can be divided into pigmentary and nonpigmentary properties. The most important function of titanium dioxide is as apigment for providing brightness, whiteness and opacity to such products as paints and coatings, plastics and rubber, paper products, cosmetics, tooth paste, printing inks, fibers and food, as well as pottery and porcelain. This function is based on a high refractive index, a measure of the ability to bend light, of the rutile polymorph of titanium dioxide. From this is attained the opacity, the ability to hide. The growing number of pigment applications are in the field of UV-light pigments in sun-blocking for people and animals, protection of wood

and plastics, food packaging, and coatings. Particle size is important for pigment applications; (200-300)nm particles exhibit a strong scattering of visible light wavelengths (400-600)nm whereas (20-50)nm crystallites scatter ultraviolet spectrum of light (200-400) nm [79]. where anatase TiO_2 can absorb ultra-violet light which has wavelength less than (387) nm because it has a band gap of (3.2 eV), but it cannot absorb visible light which is between (400)nm and (700)nm [81].

The non-pigmentary applications utilize semiconducting and dielectric properties (Rutile is investigated as a dielectric gate material as a result of its high dielectric constant ($\epsilon_r > 100$), and doped anatase films might be used as a ferromagnetic material)[80], high stability, and luminescence of TiO_2 . Examples include a photovoltaic application in solar cells, a dominant position in photocatalyst applications for oxidizing pollutants (*e.g.* formaldehyde, cyanide, DDT, aromatics, surfactants, alkenes), gas sensors, electronic insulators, high temperature catalyst supports and ceramic membranes, and optoelectronic waveguides [79].

2-10 Nanocomposite

Production of nanoparticles with controlled size and degree of aggregation is the goal of many research efforts. The primary driver for this interest is the effect of particle size on their properties. One of the advantages of using nanoparticles in a composite structure is that the particle size and distribution can be stabilized. Materials that cannot be grown easily as single crystals can be used at the nanoscale and dispersed in a polymer to take advantage of the single-crystal properties. In addition, the particles can lend properties to the polymers that they cannot achieve alone or with traditional fillers. For example, nanoparticle-filled polymers can lead to an increase in modulus and strength, but also maintain the polymer's ductility. This is because

the nanoparticles are such small defects relative to their micrometer-sized counterparts [5,82,83].

2-11 The Electrical Properties of Nanocomposite

The electrical properties of nanofilled polymers are expected to be different when the fillers get to the nanoscale for several reasons. First, quantum effects begin to become important, because the electrical properties of nanoparticles can change compared to the bulk [5,82]. where the nanomaterial can be understood in terms of the electronic properties of the bulk. In the low-dimensional system, the electronic wave functions are constrained by quantum effects in the nanoscale directions. If the nanostructure has the same crystal structure as the bulk counterpart, the electronic states of the low-dimensional system is simply a subset of the electronic states of the bulk phase. Therefore, the wave vector components in the nanoscale directions can only take discrete values so that the wave vector components become quantized [84]. Second, as the particle size decreases, the interparticle spacing decreases for the same volume fraction. Therefore, percolation can occur at lower volume fractions. In addition, the rate of resistivity decrease is lower than in micrometer-scale fillers. This is probably due to the large interfacial area and high interfacial resistance. The permittivity of polymers can also be increased with the addition of many metal oxide fillers, on both the micro and nanoscale. The use of micrometer-scale fillers for this application, however, results in a significant decrease in breakdown strength due the field concentration created by the particles. One of the significant advantages of using nanoscale fillers instead of micrometer-scale fillers may be a reduction in the loss in breakdown strength. The breakdown strength decreases for micrometer-scale fillers because of the field concentration the particles create. Nanoscale fillers do not lead to as large a reduction in breakdown strength. In addition, fundamental to controlling the breakdown

strength of insulating polymers is the cohesive energy density and the free volume or mobility of the polymer [5,82,83].

2.12 Dielectrics

A dielectric material is a non-conducting substance whose bound charges are polarized under the influence of an externally applied electric field [85]. Materials have low electrical conductivity. and use insulators to prevent the flow of the voltage to places that are undesirable or dangerous [86]. (nonmetallic) [87].The (Article dry wood, glass, plastics, rubber and ceramics) are some examples of insulators. Also dry air and oil to be used as dielectric. Separation voltage passes with difficulty because the stick electrons to the nuclei to the extent they cannot move freely from one atom to another. So when connected to the separation electrical moves electrons through the barrier sufficient to produce the current. According to the theory of energy bands for solids, a bundle valance band be completely filled in the absolute zero temperature. The Energy gap between the Valance band and the Conduction band, as show in the figure (2-2):

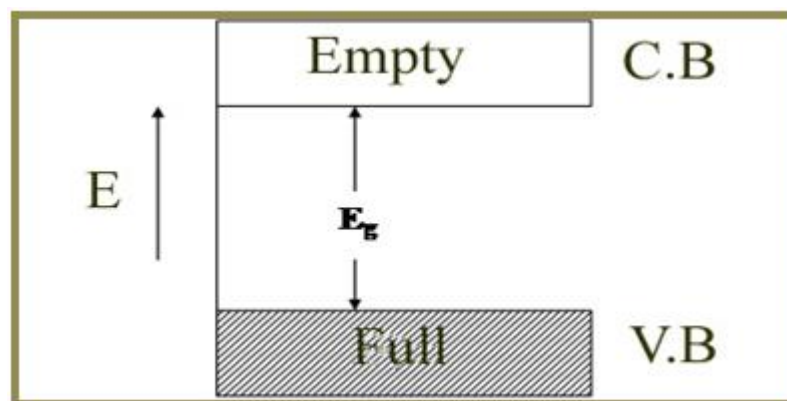


Fig. (2-2) Sketch Energy Bands at the Absolute Zero Temperature for Insulators.[86]

The depth (energy difference) of this gap may be (10eV) and above, where even if it is to 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). The energy gaps of insulators vary from material to material, In general, any material where the forbidden zone thickness is equal to more than (6 eV) be an insulator [86]. It is worth mentioning that the insulator consists of a positive charge and the other negative and often center of negative charges applying on positive charge center of these molecules, but when there are these particles under the effect of an outside electric field, the positive charge will be displaced in the direction of field while the negative charges displaced in the opposite direction, as a result, the Center of positive charge is no applying on the center of negative charges, but separated by a small distance and then say that the molecule has become induced dipole moment (polarized) [88]. But if the electric field is very large, this could lead to the acquisition of electrons of energy for conduction and so insulation broken [86,89].

The principal conditions in insulators are:

1. Having a high dielectric strength enough to withstand the electric field between the conductors poles
2. Having good resistance to movement of the spark spin-off to prevent damage in the curved electric spark.
3. Having a high insulation resistance to prevent current leakage through the conductors.
4. Being consistent under different extensive environmental conditions.
5. Having sufficient mechanical properties to resist vibrations, shocks, and other mechanical force.

Main classification for the types of insulation at the temperature can be made clear in the following table (2-1):

Table (2-1) Main category of the types of insulators at 20°C temperature.

[4,14]

Dielectrics Materials	Examples
Ceramic	Alumina, porcelain, Diamond,...etc.
Glass	Soda Lime, Pyrex,...etc.
Elastomer	Butyl,Natural Rubber, Polyurethane, etc.
Mica	
Paper (dry)	
Polymer	Acrylic, cellulose, Acetate, Melamine, Polyethylene (high density, low density), Polyvinyl chloride (rigid, flexible),...etc.

Insulators are used in many kinds of electrical and electronic equipment for example, covering wire and wire bands that conduct electricity from generating stations to homes and offices by insulators materials to prevent the current leakage. and use of insulators also capacitors to increase its capacity to store electric charge. When working in the field of equipment with high voltage, used electrical tools with handles, plastic or rubber and wear shoes with rubber soles in order to avoid damage caused by electrical shock [86].

2.13 Classification of Dielectric materials:

Through the relationship between the electric field and polarization an insulating materials can be classified to:

1- Permanent Polarization: Materials that are polarized in the absence of the electric field [90].

2- Linear Dielectric: include the materials that do not change the ability of the material for electrification and permittivity with polarization and intensity of the electric field, and each of the permittivity and electrification ability function of the position and divided into: -

A-Linear Isotropic Dielectric: although the electrification ability and permittivity do not depend on polarization and the electric field, there is a similarity in the trends, the applicability of any asymmetric electrifying and permittivity of the corresponding directions are equal, but they can remain dependent on the position [91].

B-Linear Isotropic Homogeneous Dielectric: These materials have the same qualities of insulators in the category (a) In addition; these materials do not depend on any position that the change in permittivity and electrifying scalability for the position is equal to zero [90].

3-Non-Linear Dielectric: Substances that have the existence of a functional relationship between electric field and electrical displacement and constants (the ability of the material for electrifying and permittivity), and the relationship between them is sometimes complex, the ceramics are located within this category, and include this insulations properties are: Ferroelectric, Piezoelectric property [92-94].

2.14 Polarization

Electrical insulators have very few free electrons to take-part in normal electrical conductivity. Such a material has interesting electrical properties because of the ability of an electric field to polarize the material to create electrical dipole, thus insulating material moleculars are called (Non polar molecules) [95,96]. As well as appearing dipole in a material in the presence of a field, dipoles may be present as a permanent feature of the molecular structure. Such dipoles are called (Permanent dipoles) in which the center of the positive charge does not coincide with the center of the negative charges such insulating material molecular are called (polar molecules). Induction of the dipoles is called electric polarization [97].

Phenomenon of polarization (P) down to the change in the arrangement of electrically charged particles of a dielectric in space, or is the surface charge

density in a dielectric, equal to the dipole moment per unit volume of material being defined as follow:

$$P = Nm \quad \dots(2-1)$$

where:

N: is the number of dipoles per unit volume.

m: is the average dipole moment.

The electric dipole moment corresponds to two electric charges of opposite polarity $\pm q$ separated by the distance (d)[98]:

$$m = qd \quad \dots(2-2)$$

We can represent the electrical displacement (D) as the sum of the electric field (E) at a given point of dielectric and the polarization at the same point:

$$D = \varepsilon_0 E + P \quad \dots(2-3)$$

Where:

ε_0 : is the permittivity of vacuum (8.85×10^{-12} F/m)

The relationship between the electrical displacement and the electric field through a dielectric medium is:

$$D = \varepsilon_0 \varepsilon_r E \quad \dots(2-4)$$

ε_r : is called the relative permittivity or dielectric constant of the medium, for vacuum $\varepsilon_r=1$, so

$$D = \varepsilon_0 E \quad \dots(2-5)$$

By substitute equation (2-4) in (2-3) we get [99,100]:

$$P = \varepsilon_0 \varepsilon_r E - \varepsilon_0 E$$

$$P = \varepsilon_0 (\varepsilon_r - 1)E \quad \dots(2-6)$$

2.15 Types of Polarization:

2.15.1 Electronic Polarization

Electronic polarization may be induced to one degree or another in all atoms. It results from a displacement of the center of the negatively charged electron cloud relative to the positive nucleus of an atom by the electric field. This polarization type is found in all dielectric materials and, of course, exists only while an electric field is present. as shown Figure (2-3a).

2.15.2 Ionic Polarization

Ionic polarization occurs only in materials that are ionic. An applied field acts to displace cations in one direction and anions in the opposite direction, which gives rise to a net dipole moment. As shown figure (2-3b).

2.15.3 Orientation Polarization

The third type, orientation polarization, is found only in substances that possess permanent dipole moments. Polarization results from a rotation of the permanent moments into the direction of the applied field. This alignment tendency is counteracted by the thermal vibrations of the atoms, such that polarization decreases with increasing temperature. as shown Figure (2-3c) [87].

2.15.4 Interfacial Polarization.

The final type of polarization is space-charge polarization, sometimes called interfacial polarization, and results from the accumulation of charge at structural interfaces in heterogeneous materials. Such polarization occurs when one of the phases has a much higher resistivity than the other, and it is found in a variety of ceramic materials, especially at elevated temperatures [20,101].

Other polarizations that based on the composition chemical of the material and its components and its called (Interfacial or space charge polarization), that occurs at frequencies of low little and very under audio waves, depending on the type of defects and heterogeneity that causes the polarization [102]. as shown Figure (2-3d).

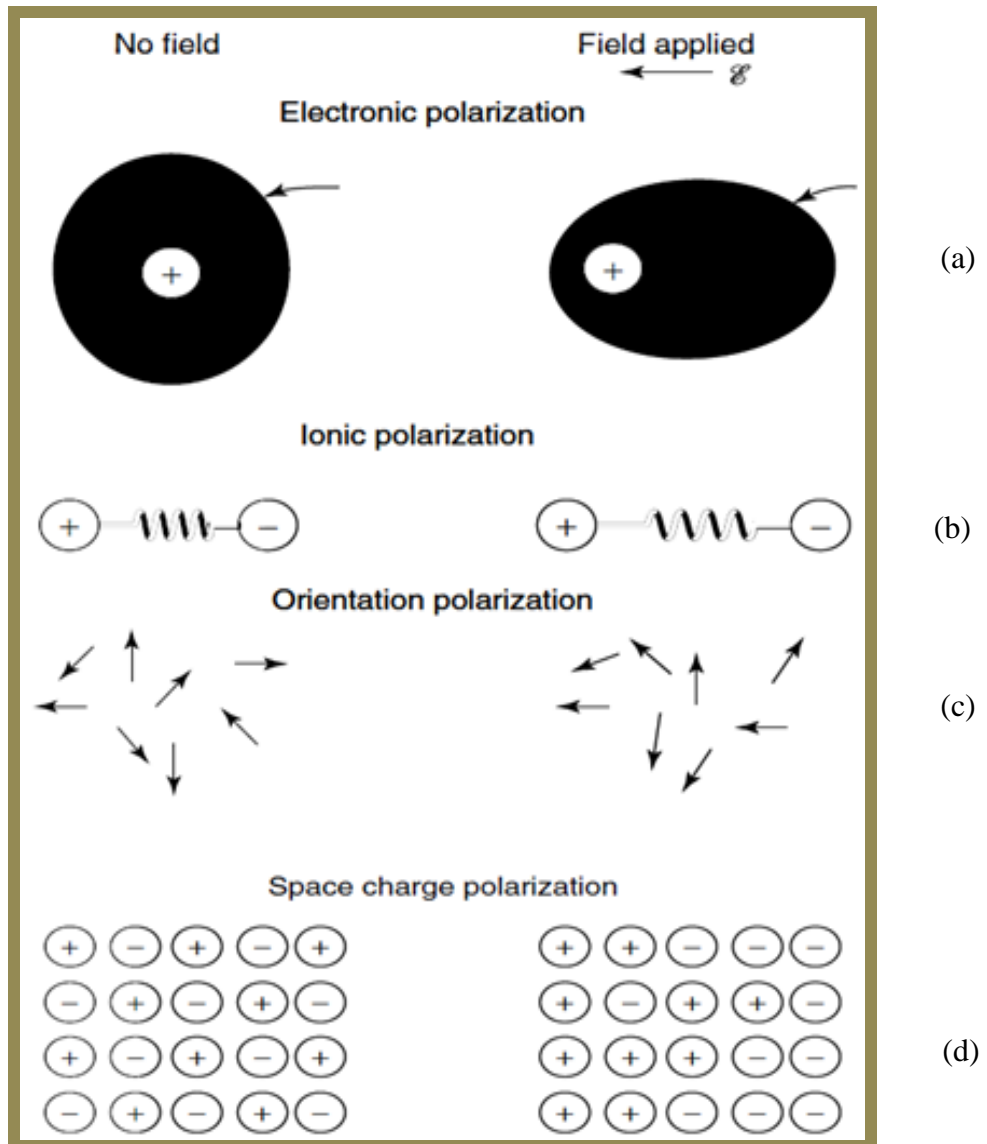


Fig. (2-3) Schematic diagram for the types of polarization.[20]

a) Electronic Polarization

b) Ionic Polarization

c) Orientation Polarization

d) Space charge Polarization

2.16 Dielectric Properties:

The outstanding feature for insulator materials in the field of electricity is the dielectric properties. Though there are many properties of dielectrics, yet the following are important from the subject of view:

1-Dielectric Constant.

2-Dielectric Loss.

3-Dielectric Strength (Breakdown Voltage).

2.16.1 Dielectric Constant

The permittivity means the charge storing capacity of a material. Consider two metal parallel plates of area (A) separated by a distance (d), in vacuum, attaching these plates to an electric circuit, the capacitance C_o of the parallel plates given by:

$$C_o = \frac{\epsilon_o A}{d} \quad \dots(2-7)$$

If a dielectric material is inserted between the capacitor plates, the capacitance (C) of the parallel plates will increase, as following:

$$C = \frac{\epsilon A}{d} \quad \dots(2-8)$$

Where:

ϵ : is the permittivity of the dielectric material.

The relative permittivity, dielectric constant, of a material (ϵ_r) defined as:

$$\epsilon_r = \frac{\epsilon}{\epsilon_o} \quad \dots(2-9)$$

Since ϵ is always greater than ϵ_o , the minimum value for ϵ_r is (1). By substitute equs. (2-9 in 2-8), the capacitance of the metal plates separated by the dielectric is

$$C = \epsilon_r \frac{\epsilon_o A}{d} \quad \dots(2-10)$$

$$C = \epsilon_r C_o \quad \dots(2-11)$$

Thus ϵ_r is a dimensionless parameter that compares the charge-storing capacity of a material to that of vacuum. Dielectric constant depends upon the frequency of the applied electric field. It decreases with the increase in frequency. Dielectric constant also depends upon temperature [87,92,103].

2.16.2 Dielectric loss

When an electric fields acts on any matter the latter dissipates a certain quantity of electric energy that transforms into heat energy. This is known as "loss" of power, i.e., the dissipation of an average electric power in matter during a certain interval of time. If a metal conductor is first connected to direct voltage and then to alternating voltage, the acting magnitude of which is equal to direct voltage, the loss of power (P_w in watt) in the conductor will be the same in both cases in conformity with the Joule-law and equal to [92,104]:

$$P_w = V^2/R \quad \dots(2-12)$$

Where V is the voltage in volt and R is the resistance of the conductor in ohms. As distinct from conductors, most of the dielectrics display a characteristic feature, under a given voltage the dissipation of power in these dielectrics depends on the voltage frequency.

The expense of power at an alternating voltage is markedly higher than at a direct voltage, and rapidly grows with an increase in frequency, voltage, and capacitance, and also depends on the materials of the dielectric.

A dielectric loss is an amount of power loss in an electrical insulator. Dielectric losses at a direct voltage can easily be found from eqn. (2-12) where R stands for the resistance of the insulator, while the losses under an alternating voltage are determined by more intricate regularities. When considering dielectric losses we usually mean the losses precisely under an alternating voltage. Let the alternating voltage ($V=V_o \exp(j\omega t)$) be applied to a circuit

containing a capacitor, with air as a dielectric medium. The current (I) passing through the capacitor according to Ohm's law.

$$I = \frac{V}{X_c} \quad \dots(2-13)$$

Where X_c is the impedance of the capacitor of a capacitance C

$$X_c = \frac{1}{Cj\omega} \quad \dots(2-14)$$

Considering the dielectric material in a capacitor (C), $\omega=2\pi f$, where, ω is the angular frequency f is the frequency

$$j=\sqrt{-1}$$

The current I may be calculated by substitute equation (2-11) in (2-14) and the result in equation (2-13) as follow,

$$I = j\omega\epsilon_r C_o V \quad \dots(2-15)$$

The current I in a dielectric is 90° advanced in phase in relation to the voltage as shown in Figure (2-4), this implies that we have a capacitive component of the current, then the heat for the system equal to zero, thus the energy is transferred in a dielectric with out losses and emission of heat "Ideal dielectric".

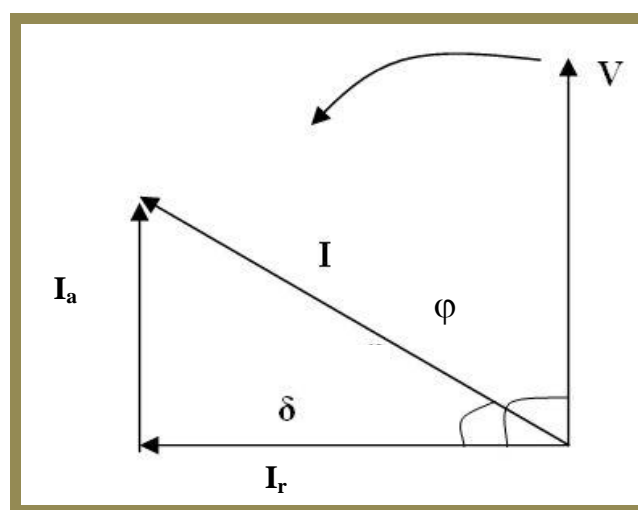


Fig. (2-4) Show simplified diagram of currents in a loss dielectric.[92]

In actual fact the phase angle φ is slightly less than 90° , the total current I through the capacitor can be resolved into two components active (resistive current) I_a and reactive (capacitive current) I_r currents [105].

The phase angle is very close to 90° in a capacitor with a high quality dielectric, the angle δ is a more descriptive parameter which, when added to the angle φ , brings the angle φ to 90° .

$$\delta = 90^\circ - \varphi \quad \dots(2-16)$$

The angle δ is the dielectric loss angle. If δ is small, therefore $\sin\delta \approx \tan\delta$. The tangent of this angle is equal to the ratio between the active and reactive currents:

$$\tan \delta = \frac{I_a}{I_r} \quad \dots(2-17)$$

$\tan\delta$ is the dielectric loss tangent or dissipation factor. It is important to note that the dielectric response of a solid can be succinctly described by expressing the relative dielectric constant as a complex quantity,

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \quad \dots(2-18)$$

In which ε_r' is the real component of dielectric constant of the material, and ε_r'' is the imaginary component, is known as the dielectric loss factor [106,107].

We can find the value of I_a and I_r by substituting equ. (2-18) in equ. (2-15):

$$I = j\omega(\varepsilon_r' - j\varepsilon_r'')C_o V \quad \dots(2-19)$$

$$I = \omega\varepsilon_r'' C_o V + j\omega\varepsilon_r' C_o V \quad \dots(2-20)$$

The total current (I) in terms of the components I_a and I_r are:

$$I = I_a + jI_r \quad \dots(2-21)$$

$$I_a = \omega\varepsilon_r'' C_o V \quad \dots(2-22)$$

$$I_r = \omega\varepsilon_r' C_o V \quad \dots(2-23)$$

By substituting equations (2-22) and (2-23) in eqn. (2-17) we can get

$$\tan \delta = \frac{\epsilon_r''}{\epsilon_r'} \quad \dots(2-24)$$

The quality factor (Q) of an insulator portion is determined, the reciprocal value of the loss tangent [108]:

$$Q = 1/\tan \delta = \cot \delta \quad \dots(2-25)$$

The expression form for the value of dielectric losses P_w in an insulation portion having a capacitance C [109]:

$$P_w = VI_a = VI_r \tan \delta \quad \dots(2-26)$$

2.16.3 Dielectric Strength

The average potential per unit thickness at which failure of the dielectric material occurs [110]. Whichever, the magnitude of the electric field required to cause dielectric breakdown is called the dielectric strength [20,111]. When applied to a strong electric field on the insulator is higher than the value of the specific critical, the relatively high electrical current will apply, So the insulation properties of the insulator will lose and become a conductor [112]. The voltage that occurs then the breakdown is called (Breakdown Voltage). When divided by the thickness of the samples [113]. As equation following [4,114]:

$$\text{Dielectric strength} = \frac{\text{breakdown voltage}}{\text{insulator thickness}} \quad (2-27)$$

$$E_{br} = \frac{U_{br}}{h}$$

$$U_{br} = E_{br} \cdot h$$

Where:

E_{br} : Dielectric strength, and calculated by units: (KV/mm) or (V/mil) [115].

U_{br} : break down voltage, h : insulator thickness.

When very high electric fields are applied across dielectric materials, large numbers 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 [87,116]. Typical dielectric strengths of polymers are in the range of (20-50)kV/mm, which are approximately (2-10) times higher than ceramics and glasses and are hundreds of times higher than conducting metals and alloys. The dielectric strength for oxide ceramic insulators lies in the range (1-20) kV/mm, with the value of (9) kV/mm for Al_2O_3 being typical[20] and dielectric Strength can be reduced by Cracks, impurities and pores [113].

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

1. Hole in the sample, which occurs when reach the real electrical durability of the insulation.
2. Burn or melt, which occurs when the material is heated locally and breakdown, occurs [117].

It is important to notice that the dielectric strength of insulation vary depending on where in the applying-voltage (d.c) give (25-30%) values higher than the voltage (a.c) at the frequency (60Hz) [118], as in NaCl, where the value of E_{br} (3.8×10^4 kV/cm) in the (d.c) while the (1.4×10^3 kV/cm) in the (a.c), and this difference can be attributed to the loss of relaxation [119]. When alternating voltage is applied on insulator, there are several phenomena that occur in the insulator from electrical conduction and polarization, as the lead increased voltages on the insulator to increase the flow of leakage current and capacitance current for alternating voltage, and upon the arrival of voltage to the greatest value, which represents the state of the breakdown of the insulator it is in this moment pass conduction current is within the insulator and increasingly after the voltage of decreasing due to reduced resistance to insulator, and this situation

often represent a circle between the source poles. The breakdown of solid insulators describe all stages of isolation, where a crash of the material, the phenomenon consists of the speed rise of the current for voltage above a certain value, can be described graphically the relationship between the current and the voltage in three regions. as in Figure (2-5) :

The first: In the region (I): - The relationship to Ohm's law with a high current linearly with increasing voltage until it reaches to the values not exceeding micro amper.

The second: In the region (II): - saturation region where the current remains constant despite increasing voltages.

The third: In region (III): - an increase in current is increasingly voltages above a certain value, which is breakdown voltage (U_{br}) [119].

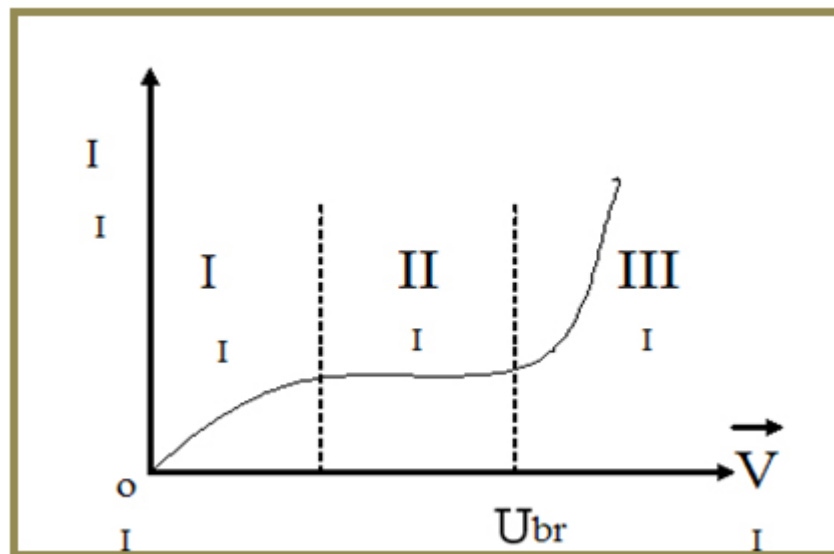


Fig. (2-5) Shows the relationship between Current and Voltage In The Solid Insulators. [119]

The mechanism of failure and the breakdown strength changes with the time of voltage application and for discussion purposes it is convenient to divide the time scale of voltage application into regions in which different mechanisms operate [120]. As shown in Figure (2-6)

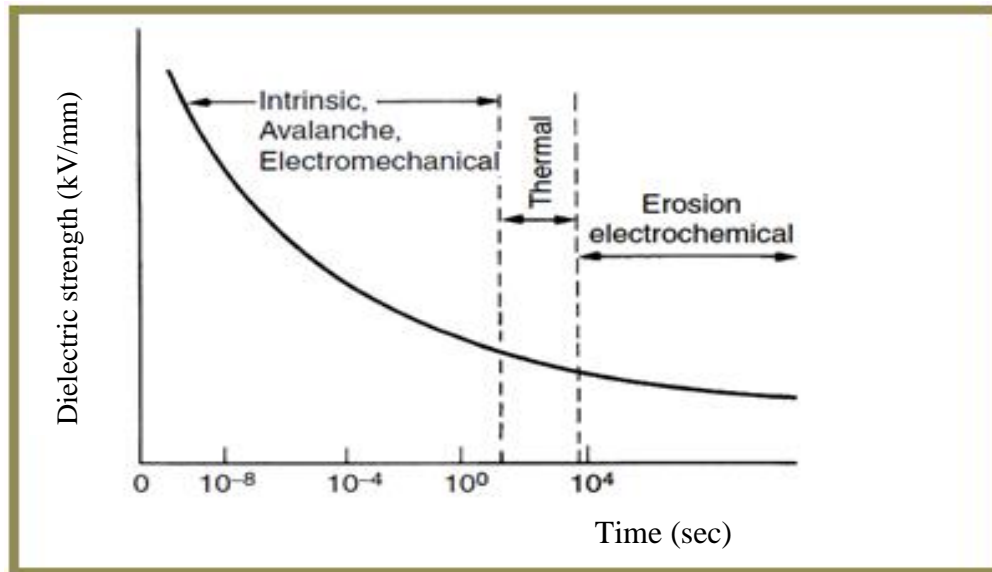


Fig. (2-6) Mechanisms of Failure and Variation of Breakdown Strength in Solids with Time of Stressing. [120]

2.17 The Main Types of Breakdown that occur In Insulators

2.17.1 Intrinsic Breakdown:

Correlate defines of The Intrinsic Breakdown to solid materials by pure material characteristics, and empty of defects under test circumstances that lead to break down at maximum voltage. The real Intrinsic Breakdown that cannot get it by experiences but the measures at low temperature and applying voltage (d.c) to short periods .it can reach to pure value [121].

This type of breakdown has to do with the presence of free electrons is a noticeable phenomenon in alkali halides, mica, glass and others. It occurs under room temperature [119]. Increasing electric intensity of the solid material rapidly under the influence of voltages very short period to the maximum that is called (**Intrinsic Electric Strength**) and get this Value practically under the best circumstances the process when removed externalities where the value depends on the type of material and the temperature only [122].

Characterized by self-breakdown of the following advantages:

1. Short time of increasing voltage up sometimes to microseconds (10^{-8} - 10^{-7})sec and the breakdown occurs at once after applying the voltage then the so-called pure breakdown.

2. The little dependence to dielectric strength and breakdown voltage with a frequency voltages and this property is necessary to compare the values of the peak voltage affecting whether a pulses or sine wave voltage.
3. If the influence of the regular electric field on insulator, the dependence of the dielectric strength on the insulator material dimensions and its pole, is a little bit [92].
4. Little dependence of the dielectric strength on the temperature [123].

2.17.2 Electrothermal Breakdown

The presence of the electric field produces a voltage applying on insulation material heat. Therefore dielectric loss continues more. Electrothermal breakdown develops as follows: voltage applied to the insulation material produces heat, which leads to raising the temperature of insulation material and the loss continues even further. The most accurate theory of the Electrothermal breakdown developed by the two Soviet researchers (Fok and Semenov). According to this theory, the breakdown voltage of the homogeneous insulator layer in a state of Electrothermal breakdown (under alternating voltage) will be equal to:

$$U_{br} = 382 \sqrt{\frac{\lambda}{f \varepsilon_i \alpha \tan \delta_i}} \varphi(\beta h) \quad (2-28)$$

Where:

U_{br} : Breakdown Voltage, (kV).

λ : Coefficient of Thermal Conductivity, (W/(m.K)).

f : Voltage frequency, (Hz).

ε_i, δ_i : Permittivity and loss angle at initial temperature before applying voltage on the insulator .

α : Thermal Coefficient of dielectric losses factor, (K^{-1}).

h : Thickness of the Insulator, (m).

β : Coefficient of describes retrieval the heat from insulator to the environment.

Where:

$$\beta = \frac{\lambda_1 \sigma}{2\lambda(\lambda_1 + \sigma h_1)} m^{-1} \quad (2-29)$$

λ_1 : Coefficient of thermal conductivity of the poles material.

σ : Coefficient of thermal conductivity from poles to the environment (W/(m².K)).

h_1 : Thickness of Pole, (mm).

When the dimensions of (βh) high and increasing, the function ($\varphi(\beta h)$) can be equal to (0.662) approximately. In the case if the poles is very thin, we assume ($h_1 = 0$) in equation (2-29) and which can get a simplified expression for the limit (β):

$$\beta = \frac{\sigma}{2\lambda} m^{-1} \quad (2-30)$$

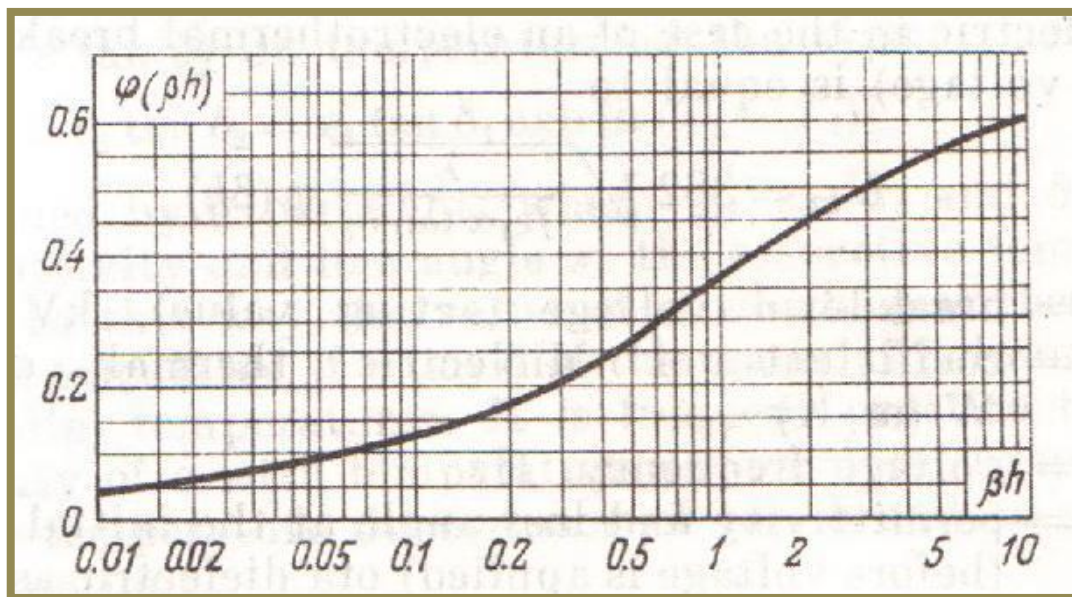


Fig. (2-7) draw to function ($\varphi(\beta h)$), and the (x-axis) logarithmic. [92]

As follows from equations (2-28) and (2-29) for the thickness of the insulating layer is very large ($h_1 = \infty$), there must be ($\beta h = \infty$) and ($\varphi(\beta h) = 0.662$), so U_{br} when ($h_1 = \infty$), is gaining a maximum specific value:

$$U_{br} = 253 \sqrt{\frac{\lambda}{f \varepsilon_i \alpha \tan \delta_i}} \quad kV \quad (2-31)$$

In the state of Electrothermal breakdown, the dielectric strength of the materials can guess its dependence on:

1. Voltage frequency, dielectric strength decreased with frequency increased.
2. The temperature, dielectric strength decreased with temperature increased.
3. The time during the application of voltage [92,120].

When applying electric field to the insulator at room temperature, so the Conduction Current is in general very little, but its value increases rapidly with the temperature of the crystal. The heat generated from the current conduction will arrive partially to the environment and absorbed in partially to raise the temperature of the crystal which in turn will increase the average generated heat. If the average of heat generation at any point in the insulator exceeds the rate of heat lost to the outside, produces then non-stabilizing and can be the sample of submission to the thermal breakdown [124,125].

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 ($\tan \delta$) and change its with temperature, and relative dielectric constant [121].

2.17.3 Electromechanical Breakdown:

During the test insulator breakdown, the poles that touched surface of the sample will shed exert forces on the sample surface by Coulomb's attractive mutual of the poles (**Coulomb attraction of the electrodes**).

Substances which can deform appreciably without fracture may collapse when the electrostatic compression forces on the test specimen exceed its mechanical compressive strength. The compression forces arise from the electrostatic attraction between surface charges which appear when the voltage

is applied. The pressure exerted when the field reaches about 10^6 V/cm may be several kN/m². Following Stark and Garton, if d_0 is the initial thickness of a specimen of material of Young's modulus Y , which decreases to a thickness of d (m) under an applied voltage V , then the electrically developed compressive stress is in equilibrium with the mechanical compressive strength if [120]:

$$\varepsilon_0 \varepsilon_r \frac{V^2}{2d^2} = Y \ln\left(\frac{d_0}{d}\right) \quad (2-32)$$

or:

$$V^2 = \frac{2Y d^2}{\varepsilon_0 \varepsilon_r} \ln\left(\frac{d_0}{d}\right)$$

Where ε_0 and ε_r are the permittivity of free space and the relative permittivity of the dielectric.

Differentiating with respect to (d) we find that expression (2-32) has a maximum when $[d/d_0 = \exp[-1/2]] = 0.6$. Therefore, no real value of V can produce a stable value of d/d_0 less than 0.6. If the intrinsic strength is not reached at this value, a further increase in V makes the thickness unstable and the specimen collapses. The highest apparent strength is then given by:

$$E_a = \frac{V_c}{d_0} = \frac{d}{d_0} E_a \approx 0.6 \left(\frac{Y}{\varepsilon_0 \varepsilon_r} \right)^{1/2} \quad (2-33)$$

This treatment ignores the possibility of instability occurring in the lower average field because of stress concentration at irregularities, the dependence of Y on time and stress, and also on plastic flow [122].

2.17.4 Streamer Breakdown

Under certain controlled conditions in strictly uniform fields with the electrodes embedded in the specimen, breakdown may be accomplished after the passage of a single avalanche. An electron entering the conduction band of the dielectric at the cathode will drift towards the anode under the influence of the field gaining energy between collisions and losing it on collisions. On occasions

the free path may be long enough for the energy gain to exceed the lattice ionization energy and an additional electron is produced on collision. The process is repeated and may lead to the formation of an electron avalanche similar to gases [120].

Figure (2-8) is shown a cross-section of a simplified example represents testing of a dielectric slab between sphere-plane electrodes. Ignoring the field distribution, i.e. assuming a homogeneous field,

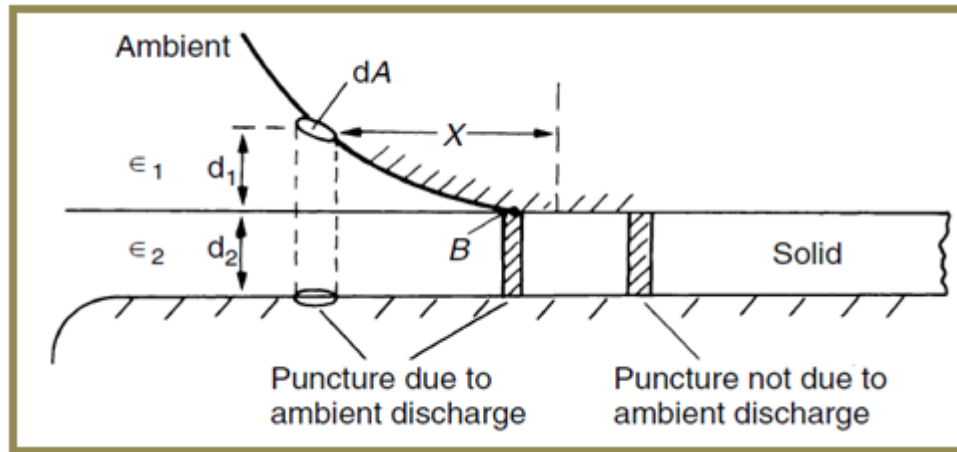


Fig. (2-8) Breakdown of Solid Specimen due to Ambient Discharge-Edge Effect. [120]

If we consider an elementary cylindrical volume of end area dA spanning the electrodes at distance x , then on applying the voltage V between the electrodes, a fraction V_1 of the voltage appears across the ambient given by:

$$V_1 = \frac{V d_1}{d_1 + \left(\frac{\epsilon_1}{\epsilon_2}\right) d_2} \quad (2-34)$$

here d_1 and d_2 represent the thickness of the media 1 and 2 in Figure (2-8) and ϵ_1 and ϵ_2 are their respective permittivities. For the simple case when a gaseous dielectric is in series with a solid dielectric stressed between two parallel plate electrodes, the stress in the gaseous part will exceed that of the solid by the ratio of permittivities. For the case shown in, the stress in the gaseous part increases further as x is decreased, and reaches very high values as d_1 becomes very small (point B). Consequently the ambient breaks down at a relatively low applied

voltage. The charge at the tip of the discharge will further disturb the applied local field and transform the arrangement to a highly non-uniform system. The charge concentration at the tip of a discharge channel has been estimated to be sufficient to give a local field of the order of (10 MV/cm), which is higher than the intrinsic breakdown field. A local breakdown at the tips of the discharge is likely, therefore, and complete breakdown is the result of many such breakdown channels formed in the solid and extending step by step through the whole thickness. The breakdown event in solids in general is not accomplished through the formation of a single discharge channel, but assumes a tree-like structure as shown in figure (2-9) which can be readily demonstrated in a laboratory by applying an impulse voltage between point-plane electrodes with the point embedded in a transparent solid, e.g. (plexiglass). The tree pattern shown in figure (2-9) was recorded by Cooper with a $1/30$ μ sec impulse voltage of the same amplitude. After application of each impulse the channels were observed with a microscope and new channels were recorded. Not every impulse will produce a channel. The time required for this type of breakdown under alternating voltage will vary from a few seconds to a few minutes. The tree-like pattern discharge is not limited specifically to the edge effect but may be observed in other dielectric failure mechanisms in which non uniform field stresses predominate [120,125,126].

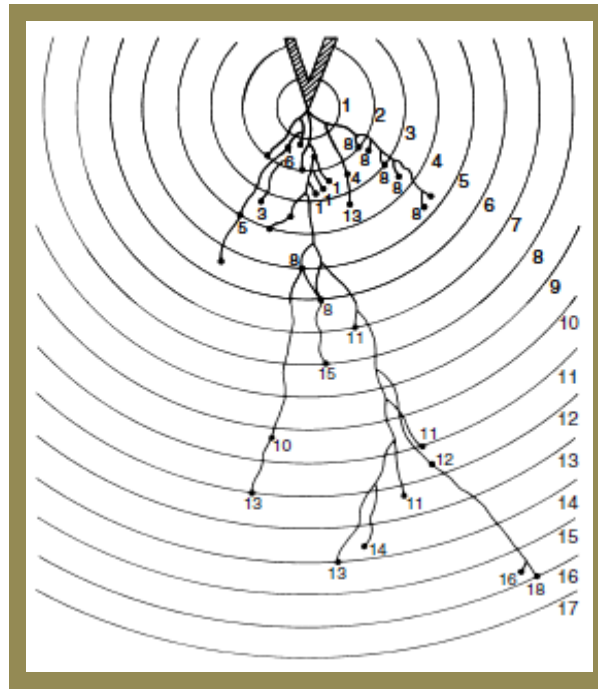


Fig. (2-9) Breakdown channels in plexiglass between point-plane electrodes.[120]

2.17.5 Erosion Breakdown

Practical insulation systems often contain cavities or voids within the dielectric material or on boundaries between the solid and the electrodes. These cavities are usually filled with a medium (gas or liquid) of lower breakdown strength than the solid. Moreover, the permittivity of the filling medium is frequently lower than that of the solid insulation, which causes the field intensity in the cavity to be higher than in the dielectric. Accordingly, under normal working stress of the insulation system the voltage across the cavity may exceed the breakdown value and may initiate breakdown in the void [120]. lately, informations level about Erosion breakdown exposed from researchers Mason and Kreuger [124,125]. Figure (2-10) shows a cross section of a dielectric of thickness d containing a cavity in the form of a disc of thickness t , together with an analogue circuit. In the analogue circuit the capacitance C_c corresponds to the cavity, C_b corresponds to the capacitance of the dielectric which is in series with C_c , and C_a is the capacitance of the rest of the dielectric.

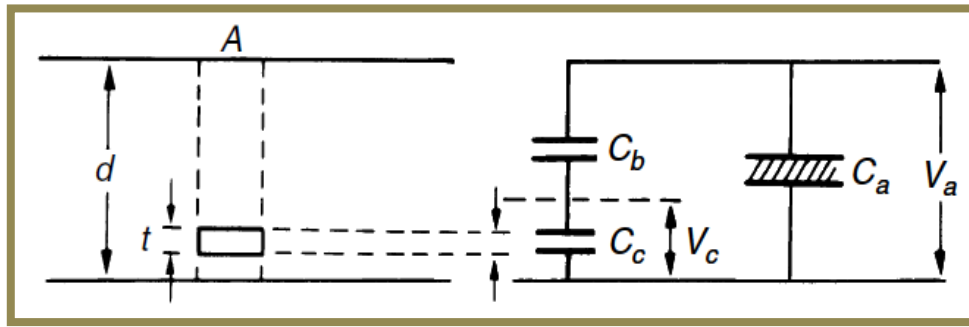


Fig. (2-10) Electrical discharge in cavity and its equivalent circuit.[120]

For $t \ll d$, which is usually the case, and assuming that the cavity is filled with gas, The voltage across the cavity is:

$$V_c = V_a \epsilon_r \frac{t}{d} \quad (2-35)$$

Where ϵ_r is the relative permittivity of the dielectric.

Under an applied voltage V_a when V_c reaches breakdown value V^+ of the gap t , the cavity may break down. The sequence of breakdowns under sinusoidal alternating voltage is illustrated in figure (2-11) The dotted curve shows qualitatively the voltage that would appear across the cavity if it did not break down. As V_c reaches the value V^+ , a discharge takes place, the voltage V_c collapses and the gap extinguishes. The voltage across the cavity then starts increasing again until it reaches V^+ , when a new discharge occurs. Thus several discharges may take place during the rising part of the applied voltage. Similarly, on decreasing the applied voltage the cavity discharges as the voltage across it reaches V^- . In this way groups of discharges originate from a single cavity and give rise to positive and negative current pulses on raising and decreasing the voltage respectively [120]. When the gas in the cavity breaks down, the surfaces of the insulation provide instantaneous cathode and anode. Some of the electrons impinging upon the anode are sufficiently energetic to break the chemical bonds of the insulation surface. similarly, bombardment of

the cathode by positive ions may cause damage by increasing the surface temperature and produce local thermal instability. Also channels and pits are formed which elongate through the insulation by the ‘edge mechanism’. Additional chemical degradation may result from active discharge products, e.g. O_3 or NO_2 , formed in air which may cause deterioration. Whatever is the deterioration mechanism operating, the net effect is a slow erosion of the material and a consequent reduction of the breakdown strength of the solid insulation [120,124-126].

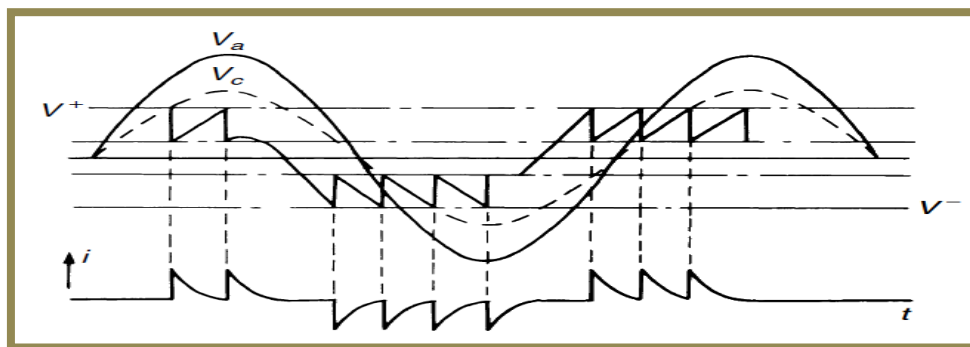


Fig. (2-11) Sequence of cavity breakdown under alternating voltages.[120]

2.18 Factors Affecting on the Dielectric Strength

We cannot describe the breakdown mechanism within a fixed factor that change with it ,because the testing requirements will change during the measurement, where the factors are interrelated and influence on each another. [92,119].

We will expose these factors as follows:

1- Internal Structure of the Insulator

Where the dielectric strength depends on internal structure of the insulator in terms of homogeneity and purity, as the presence of defects such as dislocations or interacted crystals as possible to cause the electrical connect paths, as well as the electrons that found because impurity atoms or excited heat gives the energy due to the applying field and these produce (electrons) due to atomic electronic collisions. If any of the electrons got enough energy to create a

pair (electron - hole) by electron collision of an electron, after that the extra electrons will collide and break by similar manner and breakdown happened [112].

2- Engineering and the Type of Poles

The poles between the source of high voltage and the insulator effect on the dielectric strength, where increasing the area of the poles (in comparison to the dimensions of the insulator) reduces the break voltage and that the increasing points of the penetrating of the insulator and the possibility of a break in the weakest of those points, as well as affect the geometry and the type of poles in the possibility of a burn or melt or crack in the insulator [92,119].

3- Humidity

Effect of humidity on the dielectric strength insulator, where dielectric strength decreasing when the amount of humidity content increased, the influence of humidity increases with increasing temperature [92,121].

4- Frequency

The losses in alternating fields are much higher than the continuous fields, because the loss in the relaxation phenomenon such as the movement of dipole depends on the rate of change of field, and as a result of this the intensity of Electrothermal breakdown be less of alternating fields and decrease by the source voltage frequency increase [126]. It is mention that the intrinsic breakdown doesn't depend as much as on frequency, while electrothermal breakdown depend greatly on frequency [92,119].

5- Thickness of Insulator

The dielectric strength changing with a thickness of insulator is not linear, but decrease to an increase of thickness, that prefer to measure the dielectric strength when thickness be little to estimate the value of breakdown accurately, and can explain why the decrease to the difficulty of heat recovery and taking out from the insulator to the environment, leading to increase dielectric loss and

decreased dielectric strength. Also, the increase in thickness reduces the electric field generated by the applying voltage [92,122]. As shown in figure (2-12)

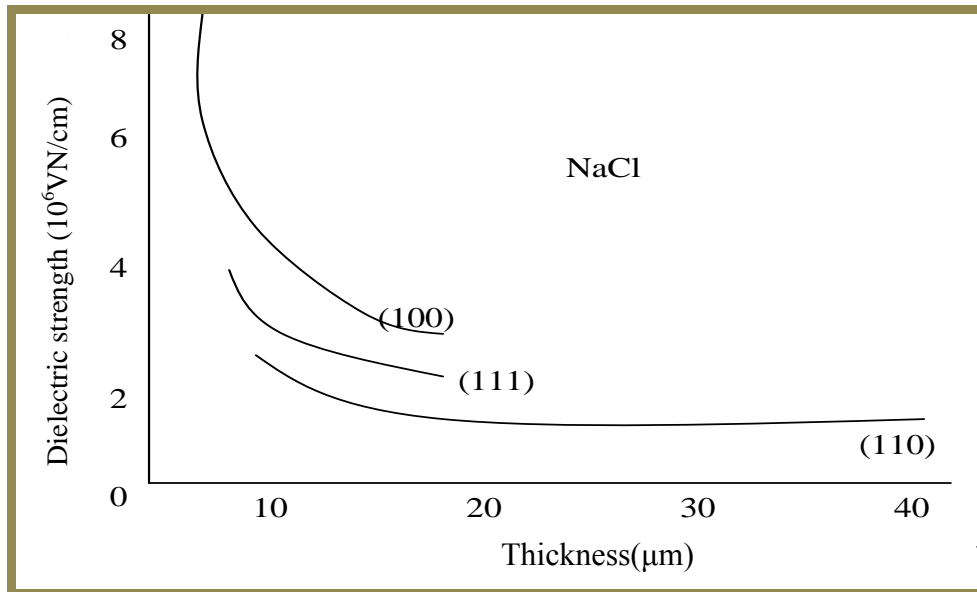


Fig. (2-12) Effect of thickness on the dielectric strength.[119]

6-Temperature

Influence of temperature on the electrical breakdown where it's in intrinsic breakdown affect on the interaction of an electron–phonon, At low temperatures ($T \ll 25^\circ\text{C}$) the phonon interactions are weak, so that the electrons gain more energy in the electric field and be able to generate many of the free electrons, and Breakdown voltage be relatively low. The Breakdown Voltage at room temperature taken maximum values where the phonon interactions are important but less than under room temperature as long as the thermal vibration can generate new electrons and the intrinsic breakdown strength less dependent on temperature. The Electrothermal breakdown is most common in the ceramic insulators the influence of the temperature effect is clear as the reasons for the breakdown can be attributed to the temperature of the environment or loss of connectivity, which generate heat at a faster rate than the rate of disposal and removal, this leads to increased local heat. In general, the dielectric strength decreases with increasing temperature as shown in figure (2-13)[119,121,127].

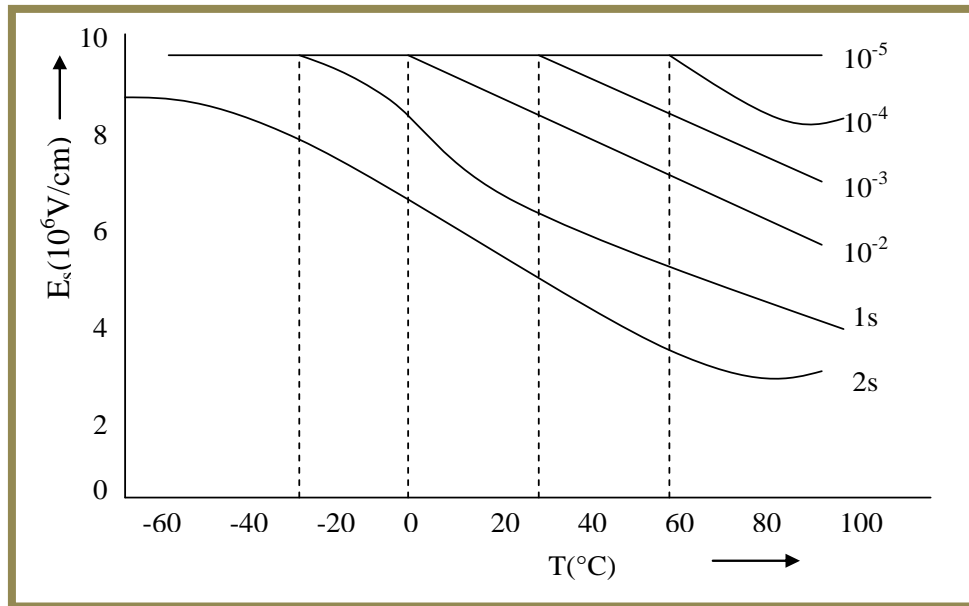


Fig. (2-13) Effect of temperature on dielectric strength.

7- Voltage Elevating Average

The voltage elevating average is a function of the dielectric strength in solid materials, where the voltage elevating average determines type of breakdown, where the range (10^{-8} -1 sec) is the extent of intrinsic breakdown, while the range (0.1- 10^3 min) is the extent of electrothermal breakdown. Where applying voltage more time increases the possibility of occurring a Electrothermal breakdown. Since the behavior of electrothermal breakdown associated with the time rate of rise of voltage, which can lead to local heat to the material as the loss of electrical power over time leads to raise the temperature more and more local connectivity, in addition to this, voltage elevating average possible cause cumulative effects of the collision (chemical and electrochemical) and corrosion, which in turn destroy the material and speeds up the breakdown by heating. Also, the increase in voltage elevating average leads to reduce the time required for two collisions consecutive for the same electron, leading to speed in a process of ionization and thus the speed of the breakdown , the lack of stability and evaporation that occurs due to the increase localized in temperature leads to the passage of high currents, which in

turn lead to hole insulator. It was found that voltage elevating average and temperature effect on the behavior of breakdown of some ceramics, where depends on the conductivity characteristics and structure. Accordingly, in the medium temperature based on voltage elevating average [105,119,121,128]. There are several from affecting factors on dielectric strength such as the time during voltage applying, samples environment, method of applying field(d.c, a.c, pulses.....etc.), samples ageing, mechanical stress, porosity...etc. [92,129,130].

3.1 Introduction

This chapter deals with the practical side of the research and includes three main points which they are: -

First: the definition of raw materials were used in the preparation of composite materials clarify the properties, general characteristics and demonstrate the importance of their role in the composite material.

Second: the reference of how to prepare templates for manufacturing composite materials, how to prepare specimens for each test and methods of testing as well as view some pictures before and after the examination and diagrams of the geometric shapes of these samples and systems of international standard established for the purpose of preparing the samples used in the research.

Third: The tests that were made in research and represent of physical testing following: -

1. Measuring the dielectric strength.
2. studying the factors influencing on the dielectric strength are:
 - A - The effect of thickness.
 - B - Effect of the voltage elevating average.
 - C - The effect of number of breakdowns.
3. Testing of the LCR meter.
4. Examination by x-ray diffraction.
5. Optical microscope examination.

With the definition of the equipment used to conduct these tests in terms of type and point of manufacture side, before turning to these points to be identified over the course of technological process steps used in the current research to form a complete idea on the progress of the production of samples and tests used in current research, and the fig. (3-1) illustrates this.

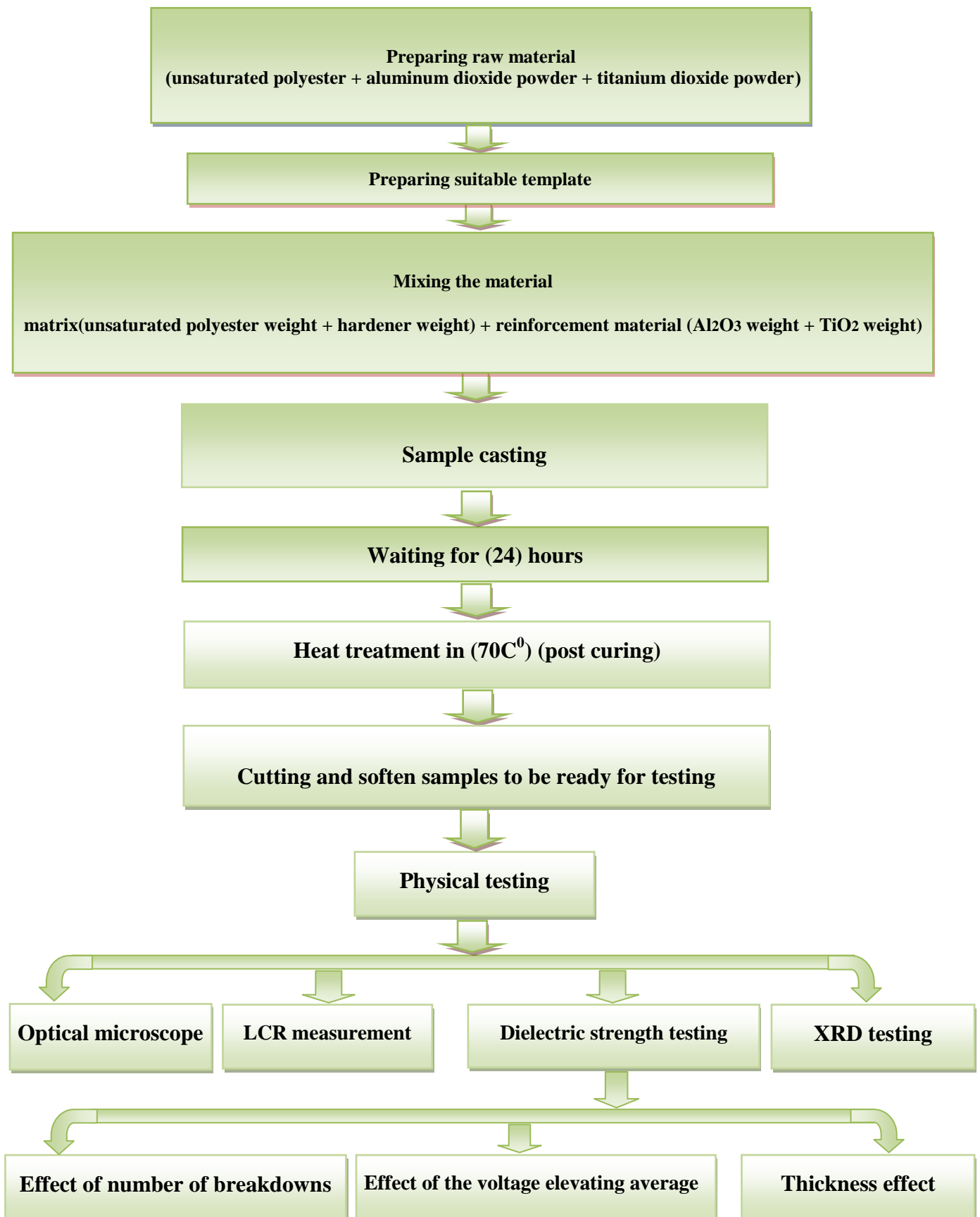


Fig. (3-1) Technological Process Steps Used in The Current Research.

3.2 Raw Materials

The materials that are used in the preparation of the research samples for this research consist mainly of matrix polymeric material (unsaturated polyester) (UP), which reinforced layer by aluminum dioxide powder and titanium dioxide powder, which are as follows:

3.2.1 Matrix Material

The Unsaturated Polyester resin (UP) used as a matrix in the preparation of polymer composite material made by (SIR) company from Saudi Arabia. This resin in the form of a viscous liquid, transparent pink color at room temperature and it is one of the types of thermosetting polymers. The resin converts from a liquid to the solid state by adding Hardener which manufactured by the same company itself is a Methyl Ethyl Keton Peroxide and is symbolized by the (MEKP) and be in the form of a transparent liquid is added to unsaturated polyester resin by rate of 2 gm per 100 gm of resin at room temperature. Motiving materials like cobalt naphthalene was used to increase the speed of hardened which interact as a catalyst called accelerators, then it was mixed directly with the resin, and it also the same company products, the way of its preparing is by the interaction of naphthoic acid with cobalt oxide. After that this liquid is added by quantity of (0.5) gm. per (100)gm. of resin. Its low cost, fast hardening and gives a violet color to the polyester resin then it helps for absorbing Ultraviolet (UV) rays which is the major factor in the hardening of the polyester. for increasing the proportion of added accelerator will lead to a hardening of abnormal for the resin (process of suddenly hardening), and when completion of the addition of hardener (MEKP) to the resin, the process of blending begin directly depending on the mixing manual for a period (10-15) minutes using the rod glass to be in homogeneity mixture, but does not favor over this period time because this will lead to make the viscosity of the mixture is very high with high temperature, which lead to accelerate the process of hardening, thereby hindering the process of pouring the mixture into the

template as well as that will make the final product content the air bubbles eventually lead to the failure of the sample so we should avoid this situation, the interaction that causes hardening of the mixture is the interaction of the emitter of heat (exothermic reaction) any emission of heat during the Cross linking process. So it should be mixing within the vessels with surface area appropriate, also a material container must be heat conducting to ensure the transmission of reactions heat to the external environment, knowing that the period of hardening of the polyester is not less than three hours at room temperature. In order to fully completing the process of hardening and reducing the rate of contractions and increased bonding between the particles of matter, and then placed the sample after hardening in an electric oven in temperature of $(60)^{\circ}\text{C}$ for a period of (90) minutes This process is called fast treatment (post curing) and after the completion of this process the sample becomes ready for a final examination, Table(1-3) shows the most important properties of unsaturated polyester that used in the research, according to the manufacturer specifications.

Table (3-1) shows the characteristics of (UP) by the manufacturer specifications.

Density gm/cm^3	Thermal conductivity $\text{W/m.}^{\circ}\text{C}$	Specific Heat J/kg. K	Coefficient of thermal expansion $10^{-6}(\text{}^{\circ}\text{C})^{-1}$	Fracture Toughness $\text{Mpa.m}^{0.5}$	Tensile strength Mpa	Percent Elongation (EL%)	Modulus of elasticity Gpa
1.2	0.17	710-920	100-180	0.6	41.4-89.7	< 2.6	2.06-4.41

And the table (3-2) shows electric characteristics to the unsaturated polyester.

Table (3-2) Shows Electric Characteristics of (UP).[20]

Resistivity	Dielectric strength	Dielectric constant, 60 Hz
1014 $\Omega\cdot\text{cm}$	15 – 20 $\text{V}/\mu\text{m}$	3.0 – 4.4

3.2.2 Reinforced Materials:

Two types of materials used in this research as reinforced Materials for the matrix material (UP) and they are: -

1- Aluminum Dioxide powder (Alumina)

The kind of aluminum Dioxide powder (Al_2O_3) with different particles sizes that used are:

The first: Micro Aluminum Dioxide powder German origin, prepared from a company (RIEDEL-DE HAEN AG). The figure (3-2) represents x-ray analysis of the micro alumina powder and the specifications show in the table (3-3).

Table (3-3) specifications of micro alumina by the manufacturer.

Density	Purity	Particle size	Type	Color
3.72 (g/m^3)	99.5	30(μm)	γ	White

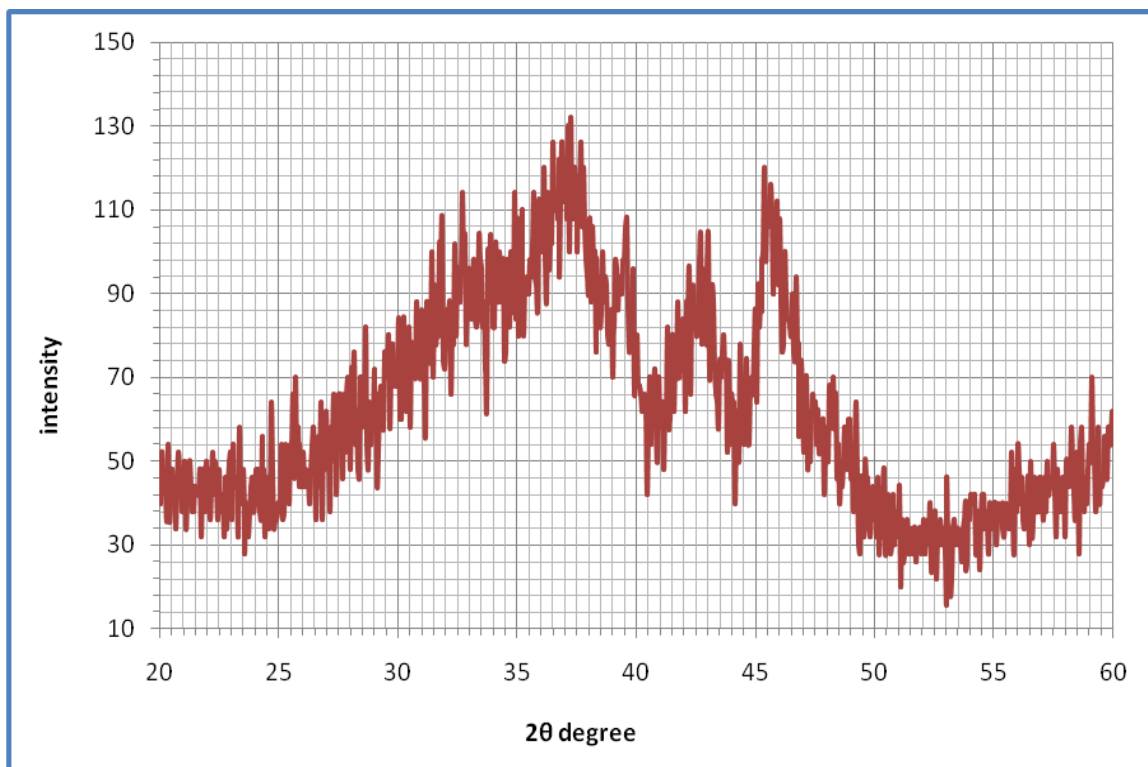


Fig. (3-2): XRD pattern for the micro gamma alumina powder

The second: Nano Aluminum Dioxide powder an American origin, prepared by (MTI) company. The figure (3-3) represents x-ray analysis of the nano alumina powder and the specifications show in the table (3-4).

Table (3-4) specifications of nano alumina by the manufacturer.

Product	Al ₂ O ₃ (white powder, alpha type, Crystalline Structure)
Particle size	30 nm
Mfg. method	SOL-GEL
Purity	99.99
Impurity (ppm)	Ca ≤ 20 , Cl ≤ 310 , Co ≤ 5 , Cr ≤ 5 , Fe ≤ 240 , Mn ≤ 5 , Na ≤ 50 , C ≤ 5.
True density	3.97 g/cm ³
Morphology	Spherical
Specific surface area	~25 m ² /g

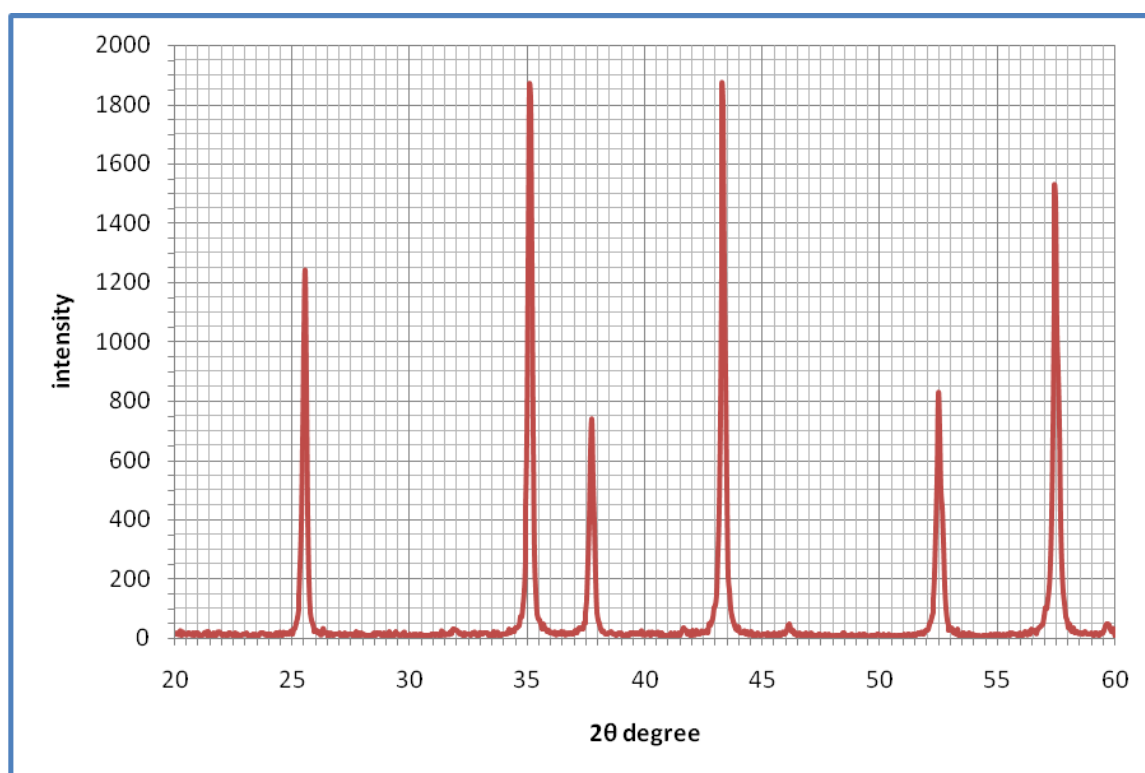


Fig. (3-3): XRD pattern for the nano alpha alumina powder

2- Titanium Dioxide Powder

The kind of Titanium dioxide Powder (TiO_2) with different particle sizes that used in this research: -

The first: Micro Titanium dioxide powder German origin, prepared by a (RIEDEL-DE HAEN AG) company. The figure (3-4) represents x-ray analysis of the micro Titania powder and the specifications show in the table (3-5).

Table (3-5) specifications of micro Titania by the manufacturer.

Density	Molecular mass	Purity	Particle size	Type	Color
$3.9(\text{g}/\text{cm}^3)$	79.9 (g/mol)	99.5	30 (μm)	α	white

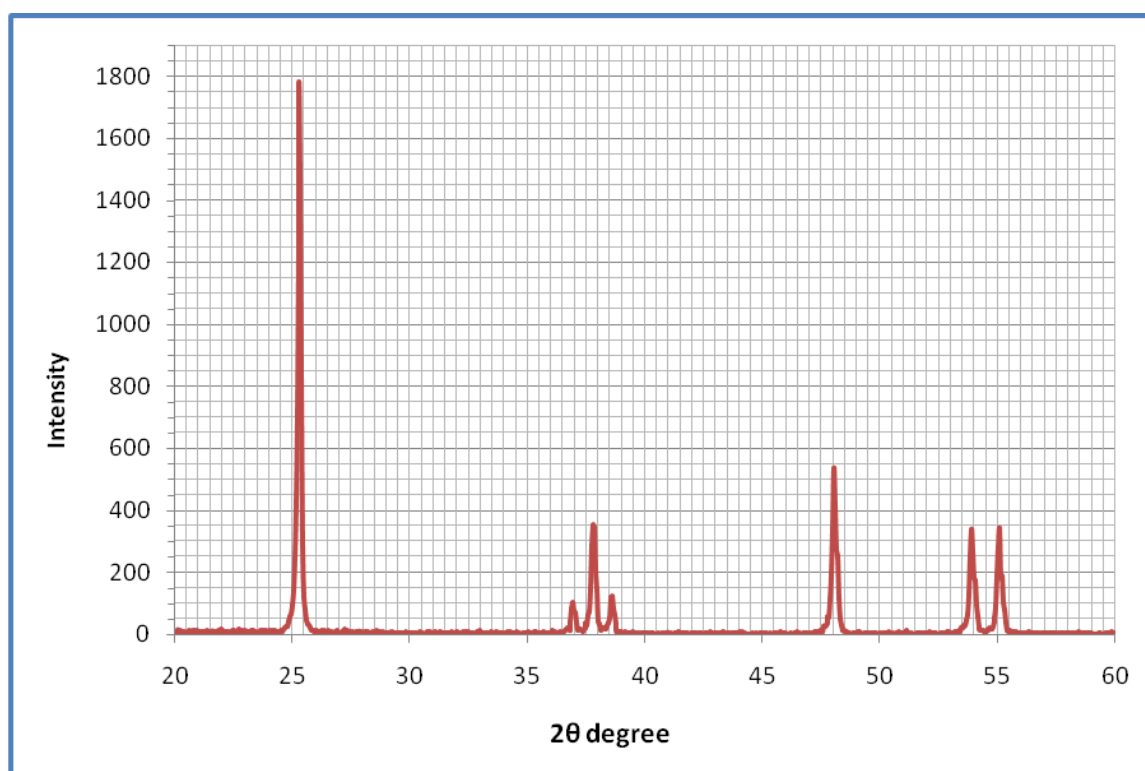
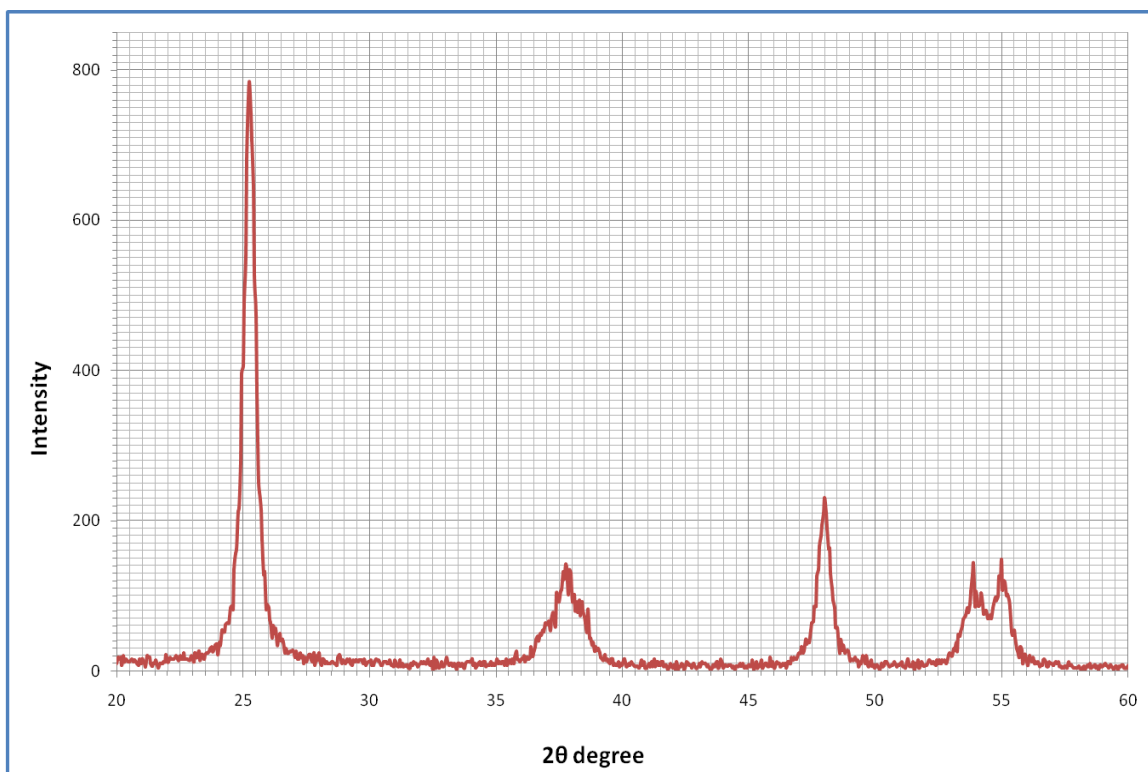


Fig. (3-4): XRD pattern for the micro titania powder

The second: Nano Titanium dioxide powder an an American origin, prepared by (MTI) company. figure (3-5) represent x-ray analysis of the nano titania powder And the specifications show in the table (3-6).

Table (3-6) specifications of nano Titania by the manufacturer.

Product	TiO ₂ (white powder, alpha type, Crystalline Structure)
Particle size	50 nm
Mfg. method	SOL-GEL
Purity	99.99
Impurity (ppm)	Al ≤ 20, Ca ≤ 75, Mg ≤ 65, Nb ≤ 119, S ≤ 165 Si ≤ 102
True density	4.2 g/cm ³
Morphology	Spherical
Specific surface area	210 +/-10 m ² /g

*Fig. (3-5): XRD pattern for the nano titania powder*

3.3 Molding Preparation

In order to mold the samples suitable molds must be prepared for forming the samples below summarizing of the process of preparing the molds:

1. Create glass base with dimensions (50×40×0.6) cm and for use as the basis for a template.
2. Create tapes glass with thickness (1,2,3,4) mm and for use as walls of the template.
3. Plating the inner surface and its borders with a thin layer of oily substance to prevent adhesion between the plastic material and mold.
4. Glass tapes are installed in opposite by thermal silicon.
5. The installation process of thermal silicon are from outside and corners.
6. After completing the process of creating the mold accuracy cleaning process and then followed by the drying process. The template is placed on a flat surface and thus be ready for the mold casting process.

3.4 Preparation of Specimens

The manufacture methods of composite materials are multiple and each one of them has advantages and disadvantages, as well as each method is applied and used in appropriate field, so the hand lay-Up Molding method used in the preparation of the samples in this research because it is a simple way to use and can from which to obtain samples of different shapes and sizes. The samples were prepared in this research are: -

1. Samples of unsaturated polyester alone only, (UP).
2. Samples of unsaturated polyester reinforced with micro aluminum dioxide, (UP+MA).
3. Samples of unsaturated polyester reinforced with nano aluminum dioxide, (UP+NA).
4. Samples of unsaturated polyester reinforced with micro titanium dioxide, (UP+MT).
5. Unsaturated polyester samples reinforced with nano titanium dioxide, (UP+NT).

The weight fraction to the reinforcement materials are (1%, 2%, 3%, 4%) and thickness of samples ranging from (1 - 4) mm.

The main method of preparation and casting the samples

For doing the above title the following steps were dependent:

1-The amount of unsaturated polyester was weighted according to the mold size, and materials were added by (0.5)%, (2)%. of motivational material and hardener were added respectively.

2-The amount of reinforced material was weighted according to the weight fraction.

3-The process of blending matrix material (UP), the catalyst, micro reinforcement material and the hardener at room temperature will be done mechanically in a continuous and slowly way in order to avoid bubbles during the mixing process, also to get an idealization diffusivity to ceramic particles in unsaturated polyester, the mixing period time is about (8-10) minutes until the mixture has been homogeneous, and the temperature rising of it will be observed which is a sign of starting up the interaction process, it is important that the mixture has a viscosity of a particular process for the purpose of protecting the deposition of the particles.

4-The nano reinforcement material mixed by using Ultrasonic equipment, because of agglomeration problem due to mass attraction that seems evident in the small particles (nanoparticle). The process of blending matrix material (UP), the catalyst and nano reinforcement material, by ultrasonic for an hour at (30 °C) and adding the hardener at room temperature will be done mechanically in a continuous and slowly way in order to avoid bubbles during the mixing process, also to get an idealization diffusivity to ceramic particles in unsaturated liquid polyester, the mixing period time is about (8-10) minutes until the mixture has been homogeneous, and the temperature rising of it will be observed which is a sign of starting up the interaction process, it is important that the mixture has a

viscosity of a particular process for the purpose of protecting the deposition of the particles. There are many of matters must be taking into account:

5- Casting the liquid mixture from the side of template (to avoid occur air bubbles in the cast, which caused a failure later) slowly until we reach the desired height so that stream will distributed to all regions of the template continuously and regularly, and here the template must be evenly completely.

6-The template is placed on an electric vibrator for shaking the mold to get rid of bubbles in the sample (if any) as well as the distribution of the composite material in all corners of the mold.

7-The cast leaved in the template for (24) hours to get harden completely, and then placed in an drying oven for an hour at a temperature (70°C), this process is important to complete the polymerization, in order to obtain a better complexity (cross link process) To remove the generated stresses from the manufacturing process. And that is called post curing.

8-To cut the samples according to the specifications of each test using an electrical saw with smooth teeth, must be sure that no vibration during cutting the samples, also the soft teeth of the saw will avoid distortions that may occur during cutting, the stage of set dimensions are using a device electric cutter and then are polishing process by soft leaves the degree of (320, 500, 800, 1200) respectively, when installed in the machine rotor smoothing.

3.5 Instrumentations

We have used in this research a set of devices for the purpose of testing the samples. These tests were take place on a standard samples at room temperature and these devices are: -

1- Mass Measurement Instrument

We have been using the sensitive balance of a high degree of sensitivity of four decimal degrees. The type of device “denver instrument“ an American origin.

2- Ultrasonic Instrument

Ultrasonic device has been used for the purpose of mixing the liquid composite materials (unsaturated polyester and nano reinforcement material). The type of device is (Power Sonic). And the specifications of the device were Korea origin, model (LUC - 410) and Temperature range (0 – 70)⁰C .

3- Dielectric Strength Instrument

The dielectric strength instrument consists of the following

1-High Voltage supplier has used with the range of voltage (0-60 kV) and frequency (50 Hz) of the type (BAUR PGO S 3) Germany origin.

2-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.

3-It contains copper poles of good electrical conduction and spherical shape, its diameter about (2mm), as in the figure (3-6).



Fig. (3-6) Dielectric Strength Instrument.

4- LCR meter

LCR meter is used to measure the resistance, capacitance, inductance, impedance, loss factor etc. of the materials. In an automatic LCR meter bridge method, the bridge circuit employs a fixed standard resistor beside the unknown Impedance and a multiplying digital to analog convertor (MDAC) that works as a resistive potentiometer. The type of LCR meter is Agilent impedance analyzer an American origin, its range of frequency (50Hz-5MHz), as in the figure (3-7).

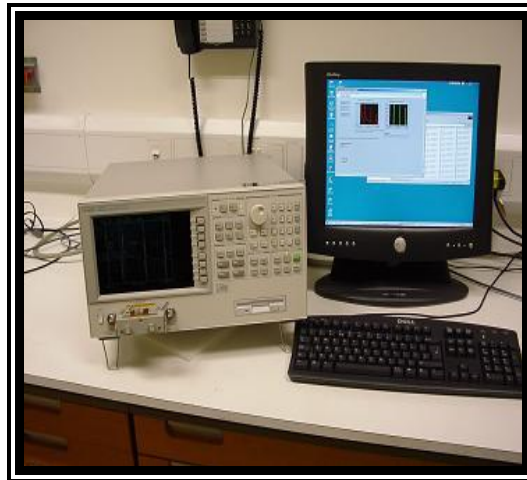


Fig. (3-7) LCR Meter.

5- Optical Microscopic Instrument

The optical microscopy was connected to a microscope with a digital camera and computer system (Model Nikon ME600, attached with digital camera DXM/200F). This system is used for photographing the samples surfaces. Which must be grinded and polished, as in the figure (3-8).



Fig.(3-8) Optical microscope.

6- X-ray Diffraction (XRD) Instrument

For studying the x-ray diffract on mode from the samples and its diagnosis for the purpose of this research, XRD equipment with the following specifications was used:

TYPE: XRD-6000, SHIMADZU, JAPANESE ORIGIN.

TARGET: Cu

WAVE LENGTH: (1.54060) Å⁰

SPEED: (5) deg / min

VOLTAGE: (40) KV

CURRENT: (30) mA

RANGE (2θ): (20-60) deg.

3.6 Electric Tests

3.6.1 Dielectric Strength

The sample put between two copper poles which are embedded in oil with make sure of touching poles with the sample surface then applying voltage through the sample that occurs the breakdown voltage. After knowing the area that breakdown happens which can be distinguish according to the damage that occur because of the breakdown. The effect factors on dielectric strength are:

1- Thickness Effect:

The effect of samples thickness on the dielectric strength with the different average elevating voltage were studied. The range of Samples thickness used were (1 - 4) mm of the samples and average elevating voltage were (0.5 - 5 kV/sec). The measurements had taken at room temperature is (27 ± 2 ° C).

2- Effect of number of breakdowns

Dielectric strength is measured of the sample from lower average elevating voltage (0.5kV/sec) to the highest (5kV/sec) with thickness (1 - 4) mm of the samples, as the applying voltage was more than once, with taking care in to the same point for each thickness and the process was repeated five times periodically.

3- Effect of the Voltage Elevating Average

Dielectric strength was measured to the samples of different average elevating voltage(0.5,1,2,3,5 kV/sec) for lower and higher thickness of the samples at room temperature, which ranged (27 ± 2 °C) during measurement taking into account not return to the area which has been examined previously.

3.6.2 Dielectric Constant

The dielectric constant measured by LCR meter which connected to computer, the sample puts between the poles and make sure that the poles touch sample surface. Dielectric constant data have recorded on computer's screen via mathematic formulas that studied previously.

3.6.3 Dispersion Factor (Tangent Loss)

The Tangent Loss was measured by LCR meter which connected to computer the sample puts between the poles and make sure that the poles touch sample surface. Dispersion factor data have recorded on computer's screen via mathematic formulas that studied previously.

4.1 Introduction

This research includes expose and discussion the physical testing to (Dielectric strength, Dielectric constant, x-ray analysis and optical microscope pictures) supported by diagrammatic planning and illustrating figures to the samples of unsaturated before and after reinforcement by particles. the general behavior was similar to all weight fractions, so I didn't put illustrate charts to (2%, 3%) weight fractions.

4.2 Dielectric Strength

Effect factors on the Dielectric strength are:

4.2.1 Effect of Thickness

The figures (4-1),(4-2),(4-3),(4-4),(4-5) explain the effect of thickness on the dielectric strength of the samples prepared from composite material that has plastic matrix (Unsaturated Polyester) reinforcement by micro and nanoparticles alumina with weight fraction (0%, 1%, 2%, 3%, 4%), respectively, and different thicknesses, it was observed that there a decrease in dielectric strength with increasing of dielectric thickness due to several reasons which are :

First: The breakdown voltage in units (kV) does not change linearly with the increase in thickness, because the insulator material decrease the influence of electric field because of the insulator response to the electric field by method of polarization therefore, the influence increases and the decrease of the external electric field with increasing of thickness of the insulator. the effect of increased in leakage currents grow up from crystalline defects as holes (cavity) which show significantly when casting samples of polymer, dislocations, interference of crystalline and impurities of metals oxides that generate electrical conductivity paths leads to the appearance of electric breakdown at early time and decrease in dielectric strength also, the difficulty of heat recovery and throw it from the insulator outside. These factors lead to decrease the Dielectric strength, as these impurities contribute to influence on the crystal structure, because the additions influence on the chemical bonds, as well as increase the

charge carriers by providing electrons or ions to the conduction process. The increasing in porosity and electrical conductivity leads to a decrease in the values of the dielectric strength.

Second :The dielectric strength are affected significantly by loss factor where the dielectric strength decreases with increasing of loss factor, thus increasing the thickness and the presence of crystalline defects lead to increased in loss factor which due to increased leakage currents and connectivity within the composite material. also, the increase in thickness reduces the electric field which is generated by applied voltage. the dielectric strength increase linearly with breakdown voltage according to electric insulation equation:

$$\text{Dielectric Strength} = \frac{\text{breakdown voltage}}{\text{insulator thickness}}$$

so a decrease of the electric field with thickness increase cause a decrease in dielectric strength.

Third: The presence of these impurities under the influence of an electric field and being charged, will transfer it through the crystal and making it easy to trap. thus it lead to pile up charges that operate to induce opposite charges on the other side which cause grow up of dipoles in the composite material which is called the Interfacial or Space Charge Polarization. When a comparison between the values of the dielectric strength of the micro polymer composite and the values of the dielectric strength of the nano polymer composite, we note that the values of Dielectric strength are approach by addition of micro aluminum dioxide and nano aluminum dioxide[92,119,122].

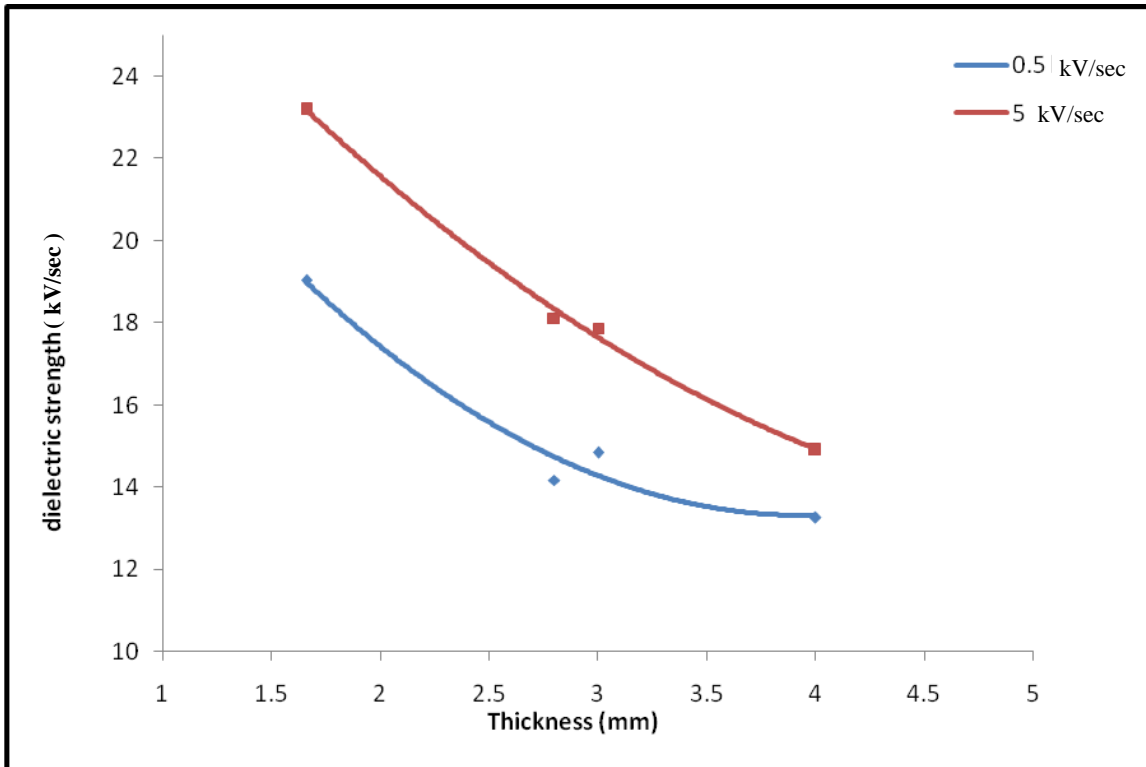


Fig. (4-1) Dielectric strength versus thickness (UP)

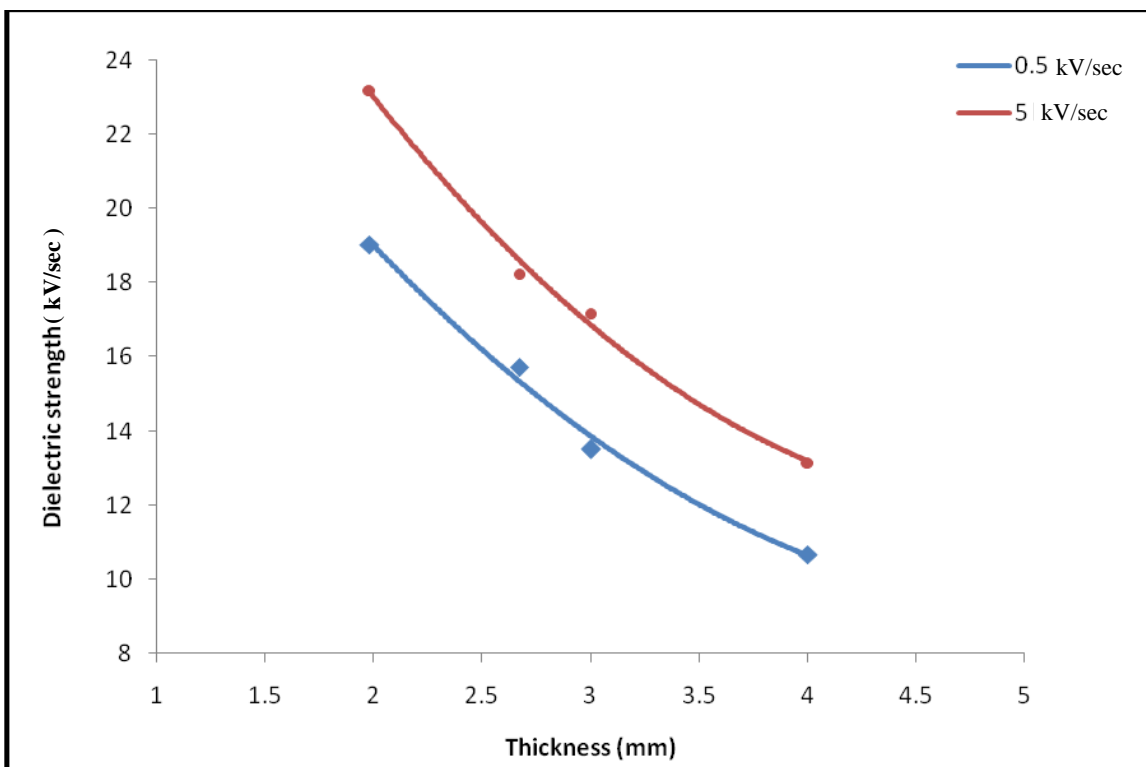


Fig. (4-2) Dielectric strength versus thickness (UP+1% MA)

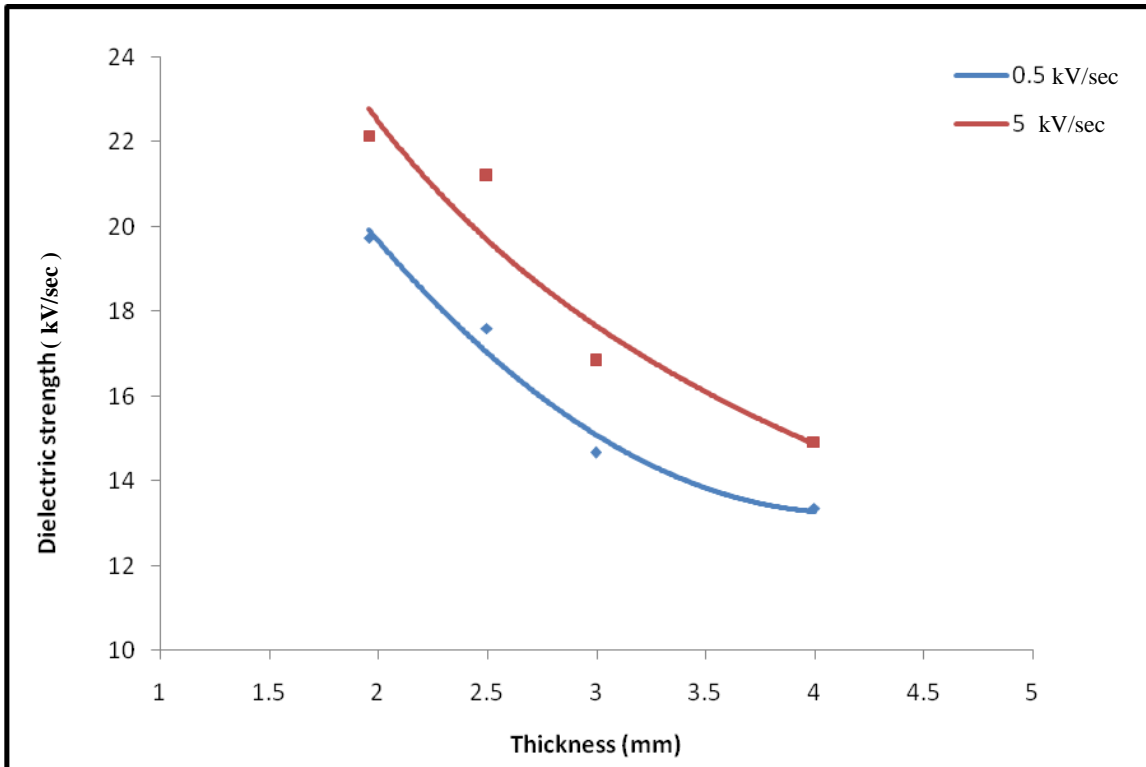


Fig. (4-3) Dielectric strength versus thickness (UP+4% MA)

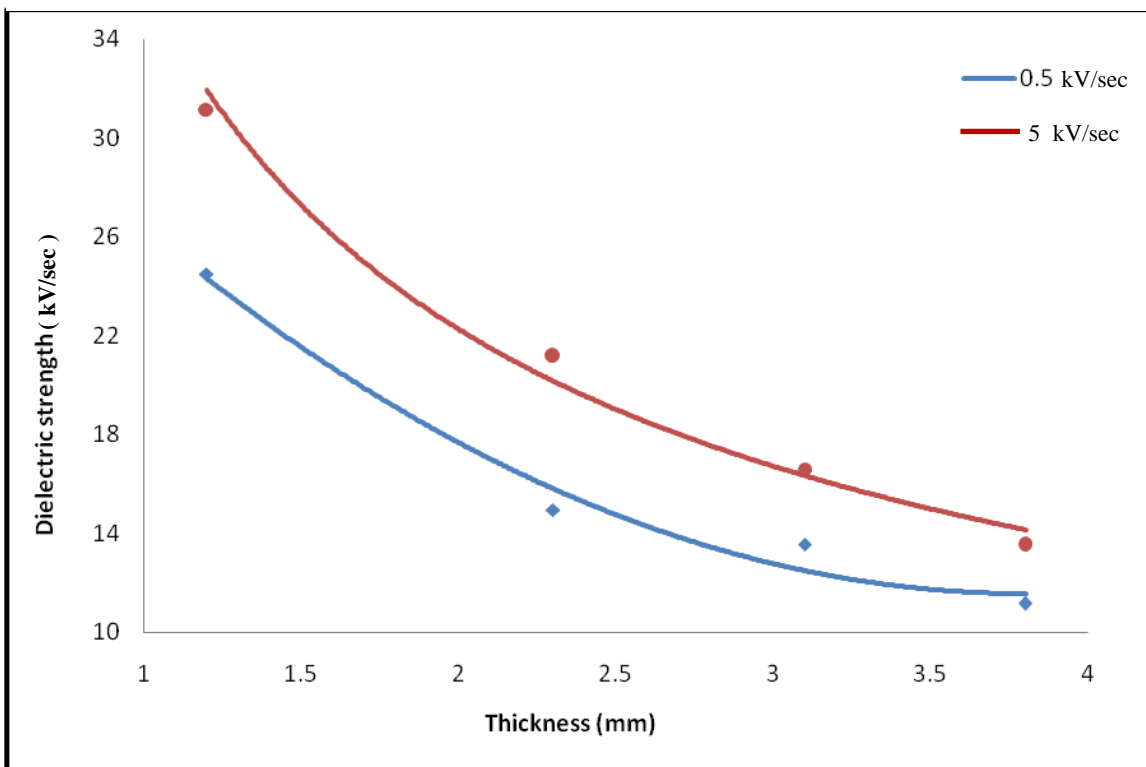


Fig. (4-4) Dielectric strength versus thickness (UP+1% NA)

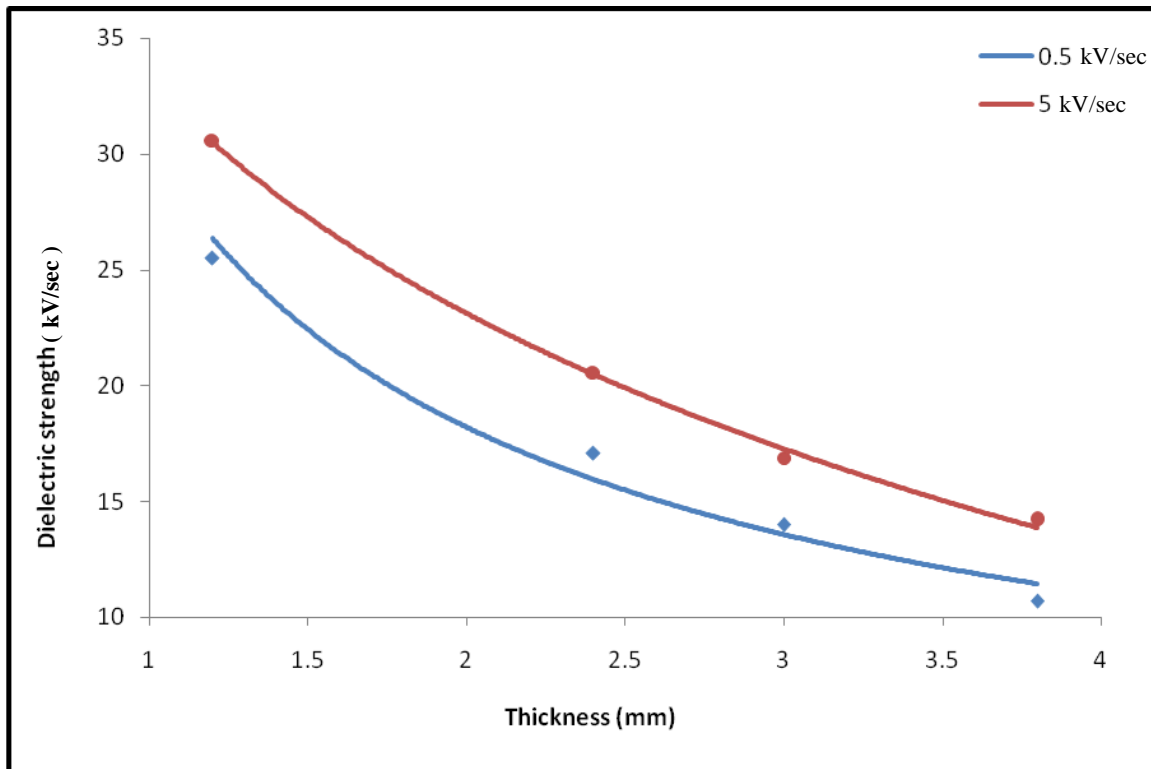


Fig. (4-5) Dielectric strength versus thickness (UP+4% NA)

4.2.2 The voltage elevating average

The figures (4-6), (4-7), (4-8), (4-9), (4-10), (4-11), (4-12), (4-13), (4-14), explain the change in the dielectric strength with the The voltage elevating average of micro and nano polymer composite samples of aluminum dioxide and titanium dioxide ((UP + alumina), (UP + titania)) at the same previous weight fraction . It is observed that the increase of dielectric strength with the increase in the voltage elevating average as the slow voltage elevating average (0.5kV/sec) leads to increased in heat raised from the leakage currents, where the applying voltage for a long time increases the possibility of occurrence of 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 The voltage elevating average. The reasons behind decrease of dielectric strength with a decrease in average time to increase the voltage occurs 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. The values that we get from the high rates increasing represent the time of opening or closing the circuit, which contain in its application such electrical insulators. The increase in the voltage elevating average leads to reduce the time required for two consecutive collision of same electron due to the acquisition of electrons to sufficient energy leading to speed the process of ionization and thus speed the breakdown resulting in an increase in the values of dielectric strength. 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. We cannot be re-tested once again to the same sample because of this test is one of the destructive. 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[105,119,121,128].

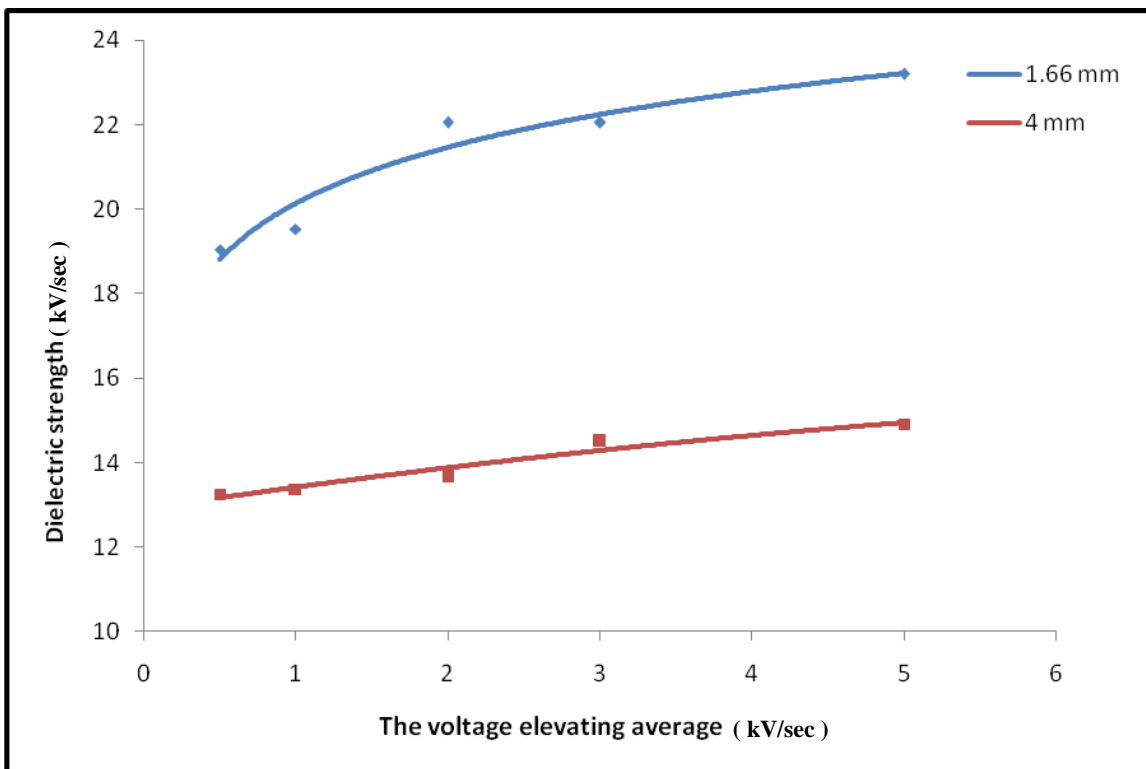


Fig. (4-6) Dielectric strength versus voltage elevating average (UP)

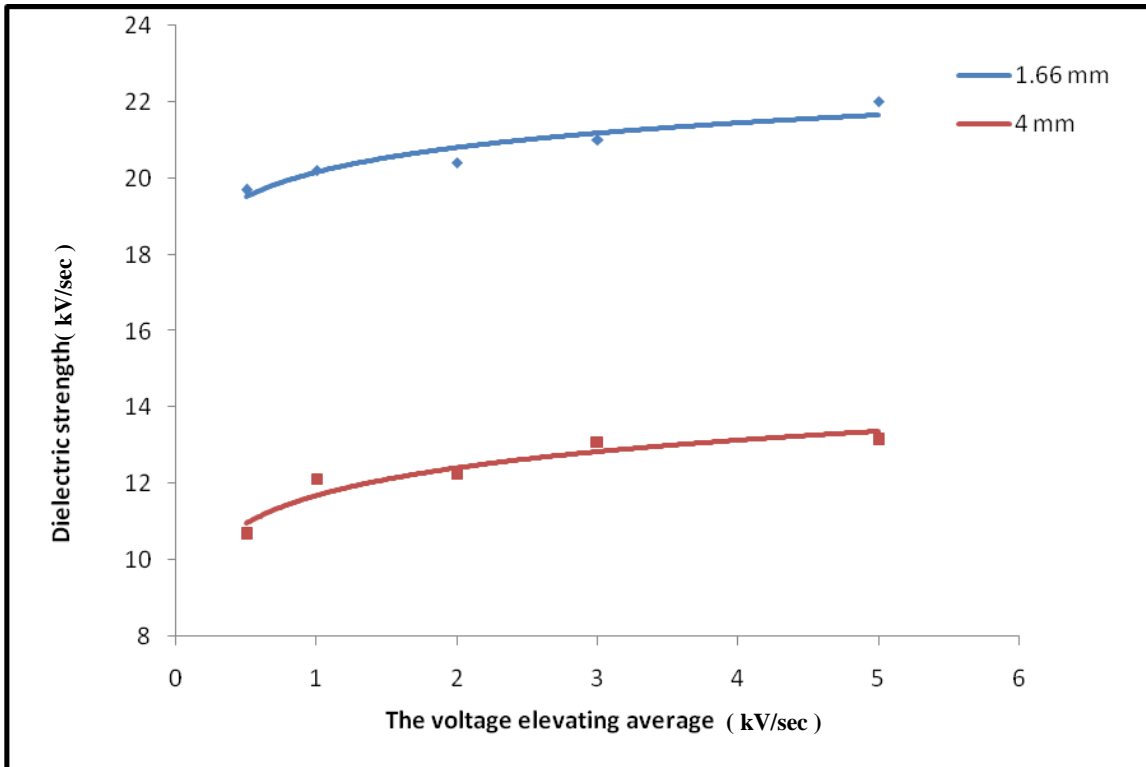


Fig. (4-7) Dielectric strength versus voltage elevating average (UP+1% MA)

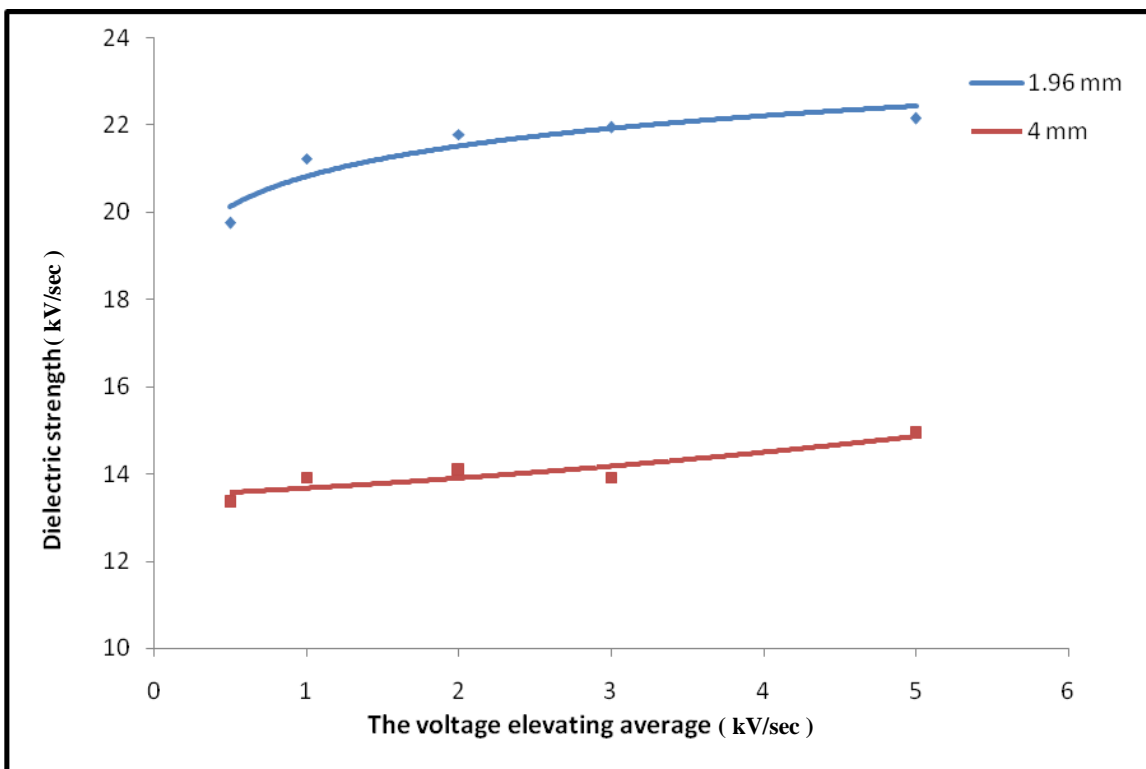


Fig. (4-8) Dielectric strength versus voltage elevating average (UP+4% MA)

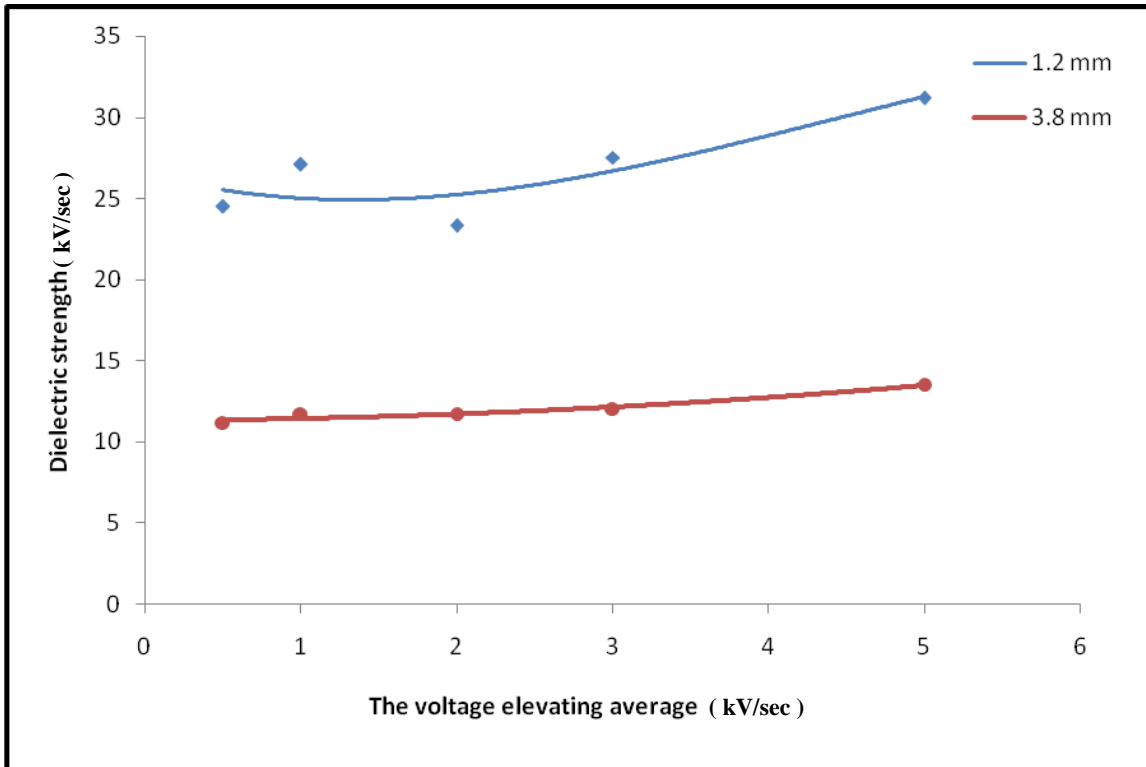


Fig. (4-9) Dielectric strength versus voltage elevating average (UP+1% NA)

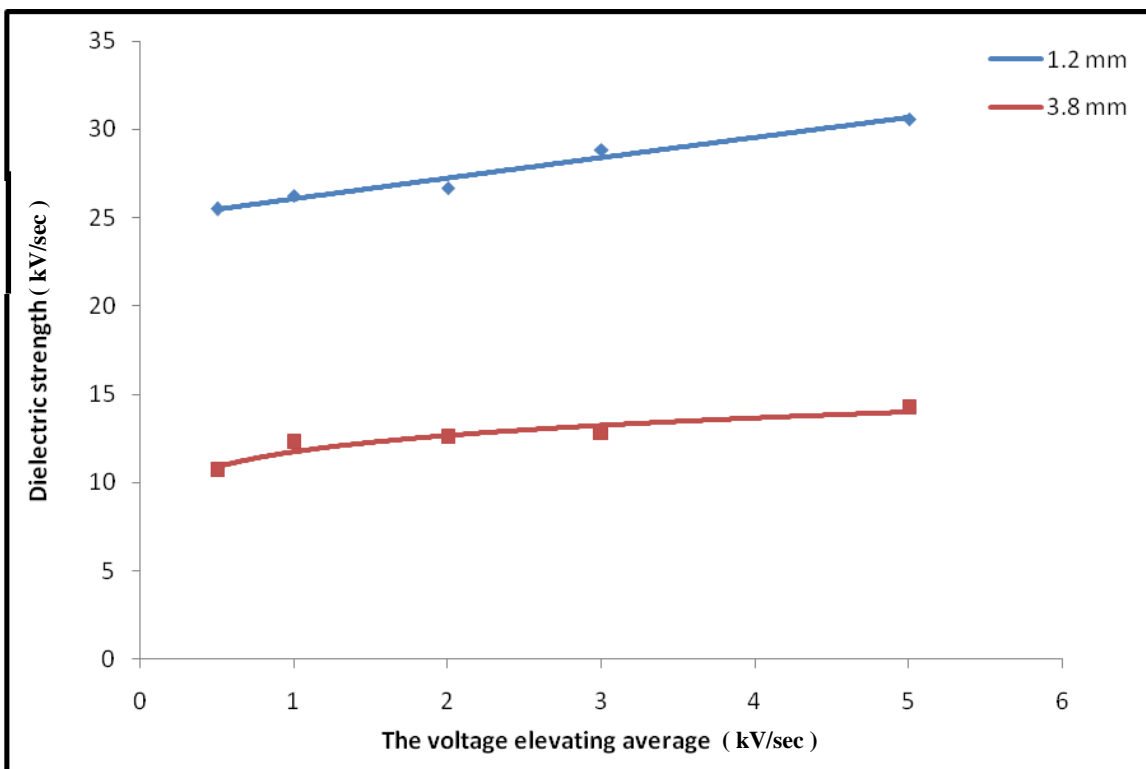


Fig. (4-10) Dielectric strength versus voltage elevating average (UP+4% NA)

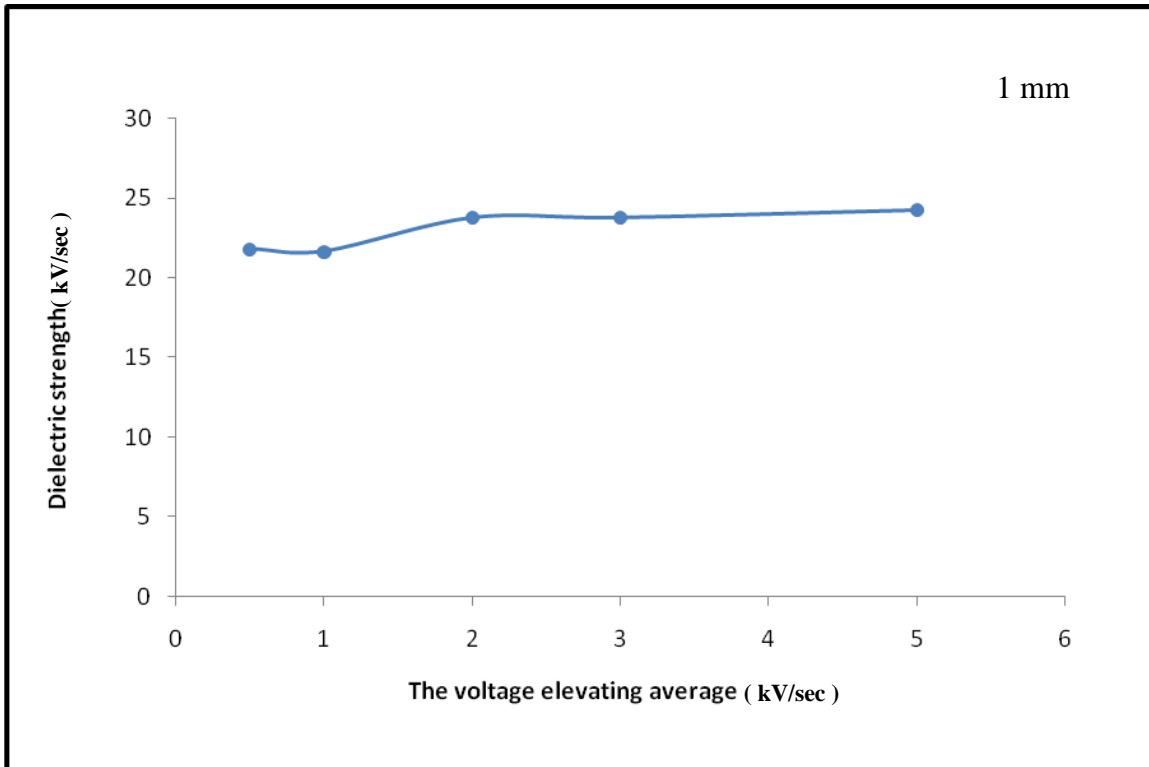


Fig. (4-11) Dielectric strength versus voltage elevating average (UP+1% MT)

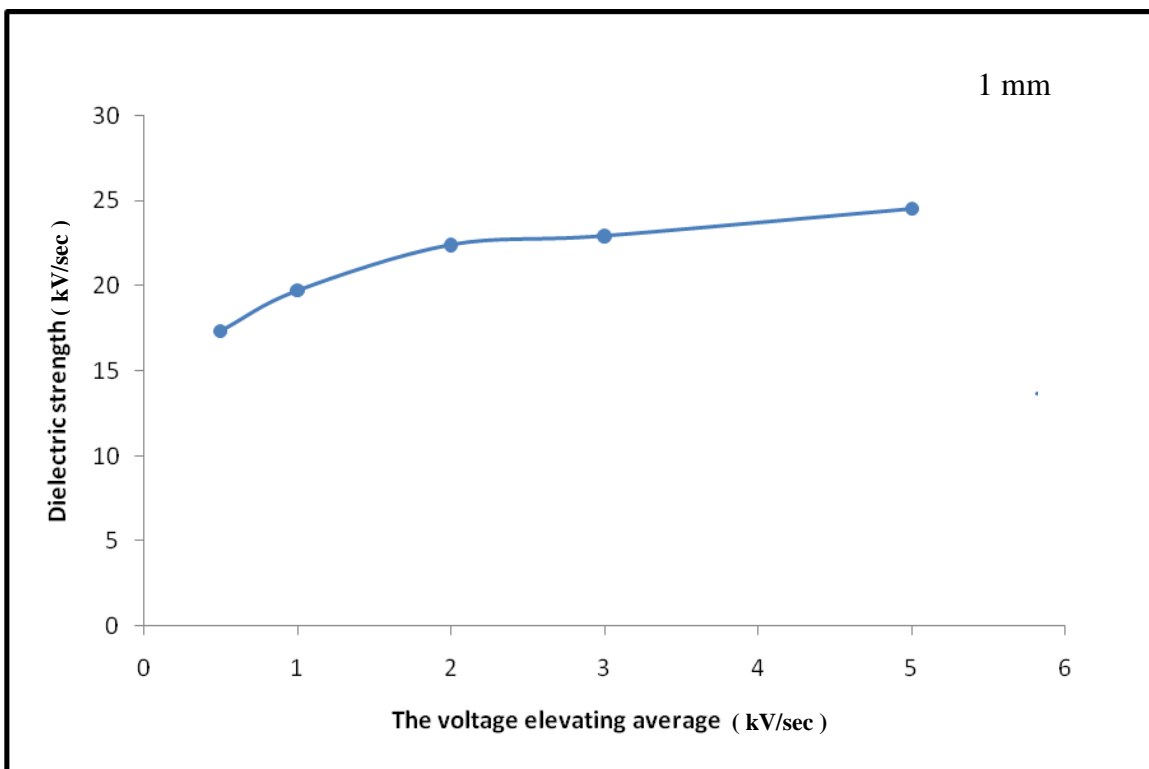


Fig. (4-12) Dielectric strength versus voltage elevating average (UP+4% MT)

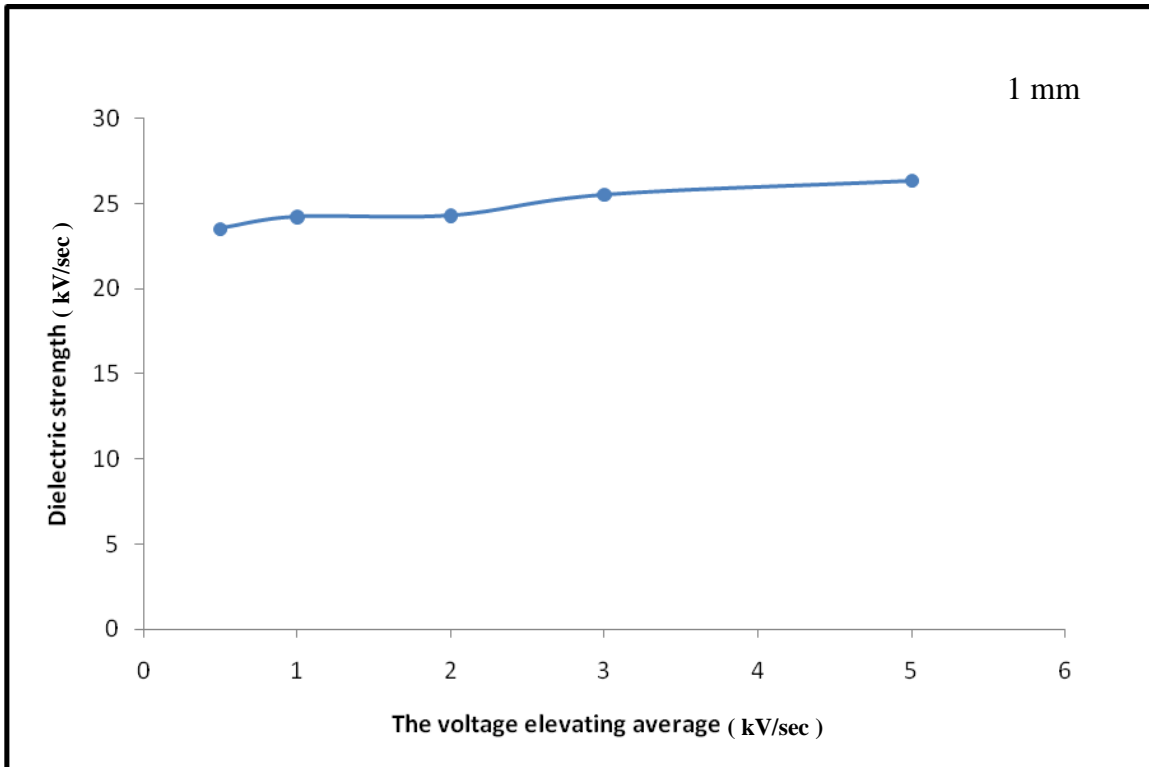


Fig. (4-13) Dielectric strength versus voltage elevating average (UP+1% NT)

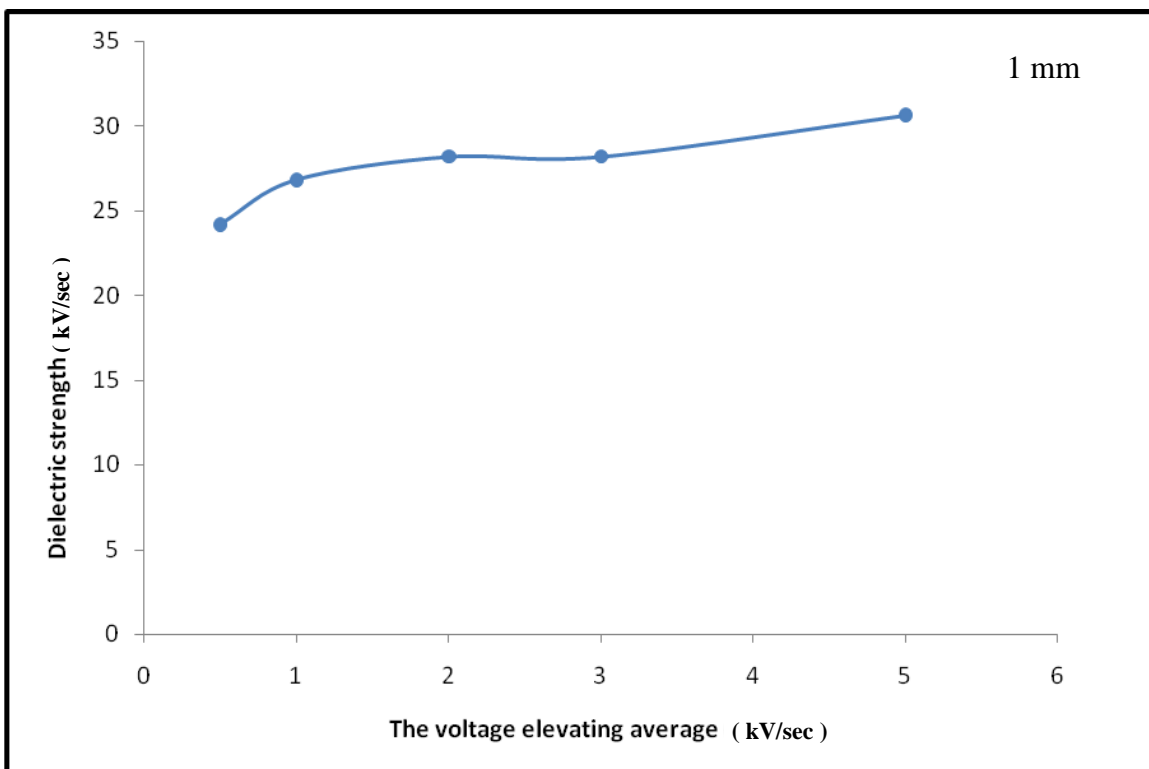


Fig. (4-14) Dielectric strength versus voltage elevating average (UP+4% NT)

4.2.3 The Effect of the Number of Breakdowns

The test of dielectric strength change with the number of breakdowns which is one of the tests that can know the possibility of use electrical insulators with the electric breakdown and recycle it again in the practical applications that need less voltage.

The figures (4-15), (4-16), (4-17), (4-18), (4-19), (4-20), (4-21), (4-22), (4-23), describe the change in dielectric strength with the number of breakdowns for micro and nano composite polymer reinforced by aluminum dioxide and titanium dioxide ((UP + alumina), (UP + titania)) and the same previous weight fraction. We note a sharp decrease in the dielectric strength, especially at small thickness, It is possible that the reason is attributed to the large chemical changes that appear with the diffusion of electric spark, because the material test leads to burn the material or puncture it at the point of test and therefore the loss of the dielectric property of the material and thus become conductive. In the large thickness of breakdowns number be less in small thickness due to few chemical changes through diffusion of electric spark. The anomaly tests of some points from the general behavior of the test because the defects arising in the samples of composite material, 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 the 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 decreased in dielectric strength in the second round to half of the value of the first round, which cause a significant decrease up to 90% in the second round if compared with dielectric strength value in the first one[93].

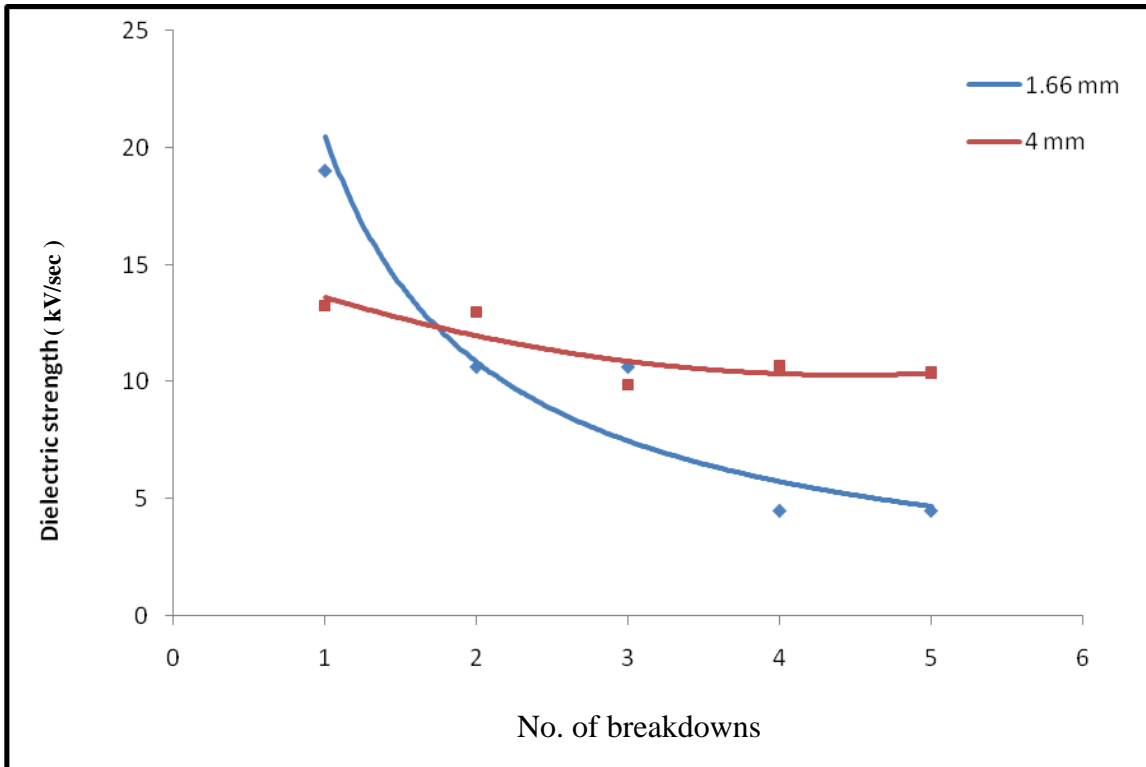


Fig. (4-15) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP)

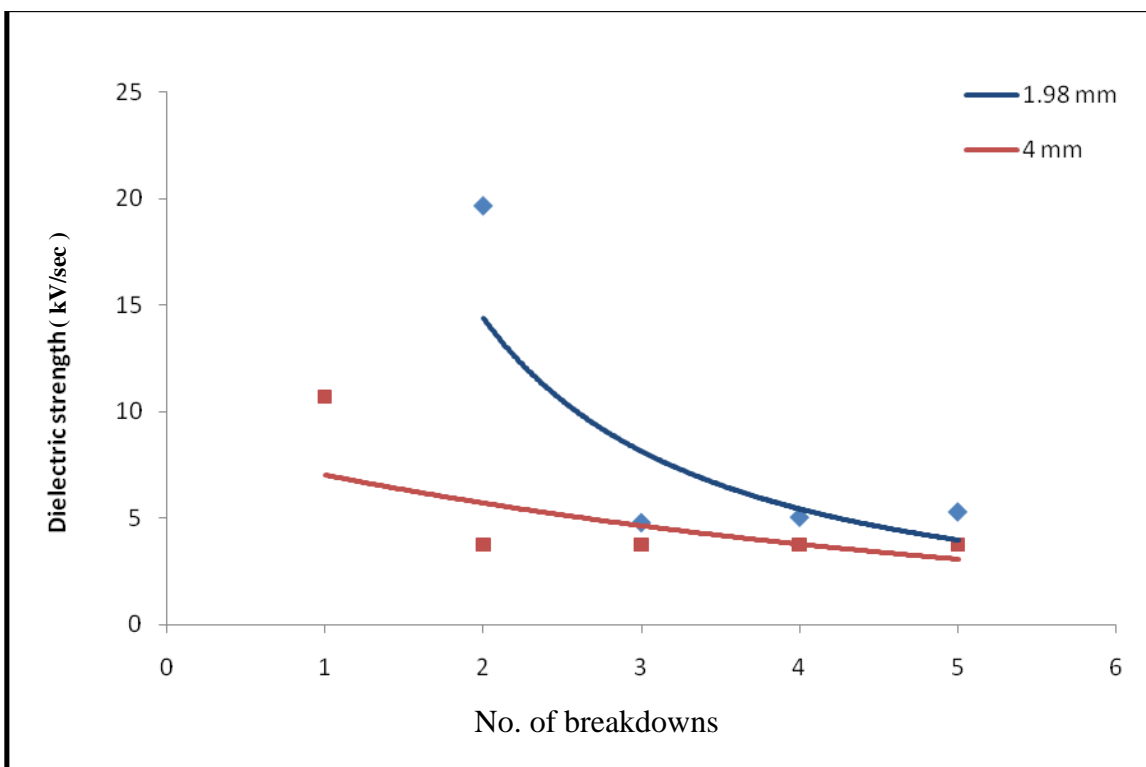


Fig. (4-16) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1%MA)

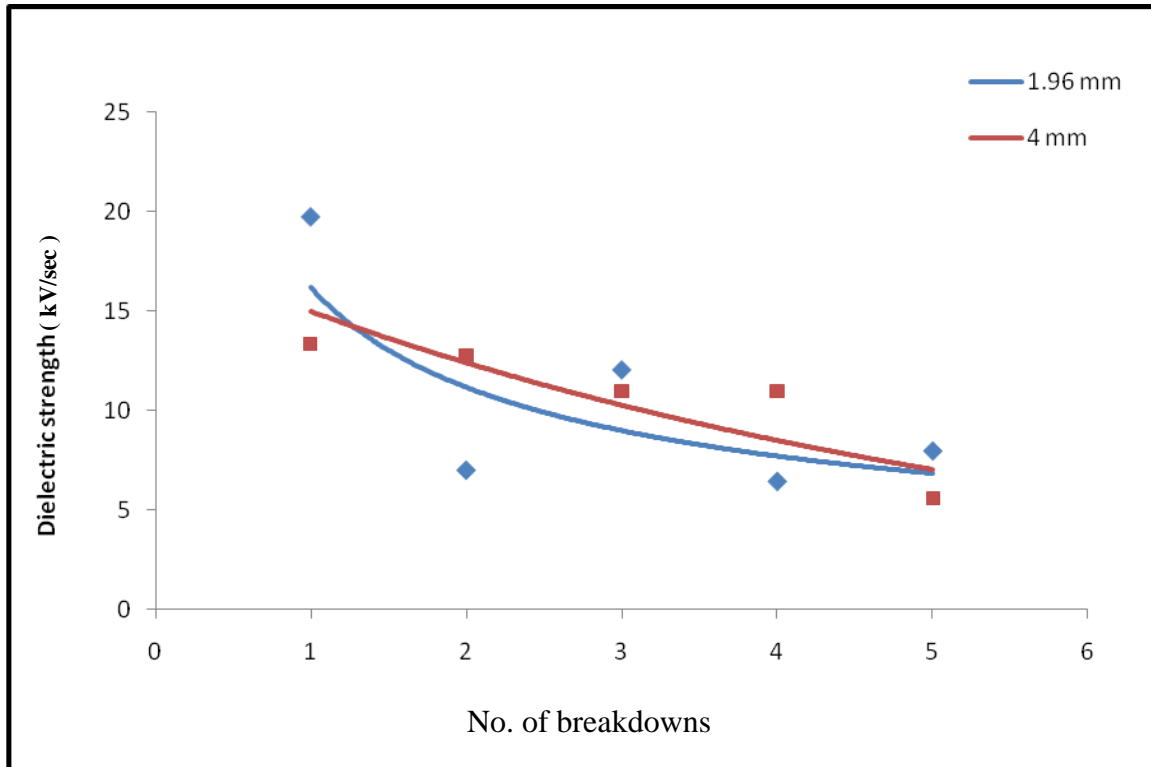


Fig. (4-17) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4%MA)

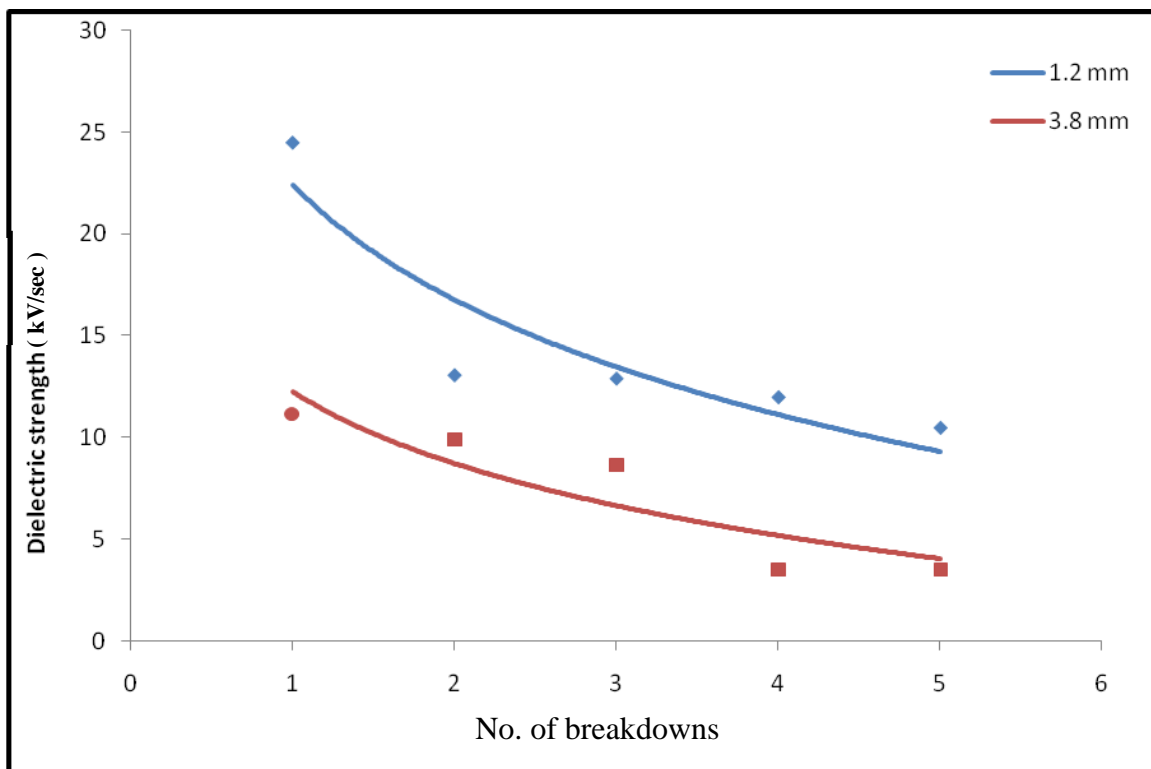


Fig. (4-18) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% NA)

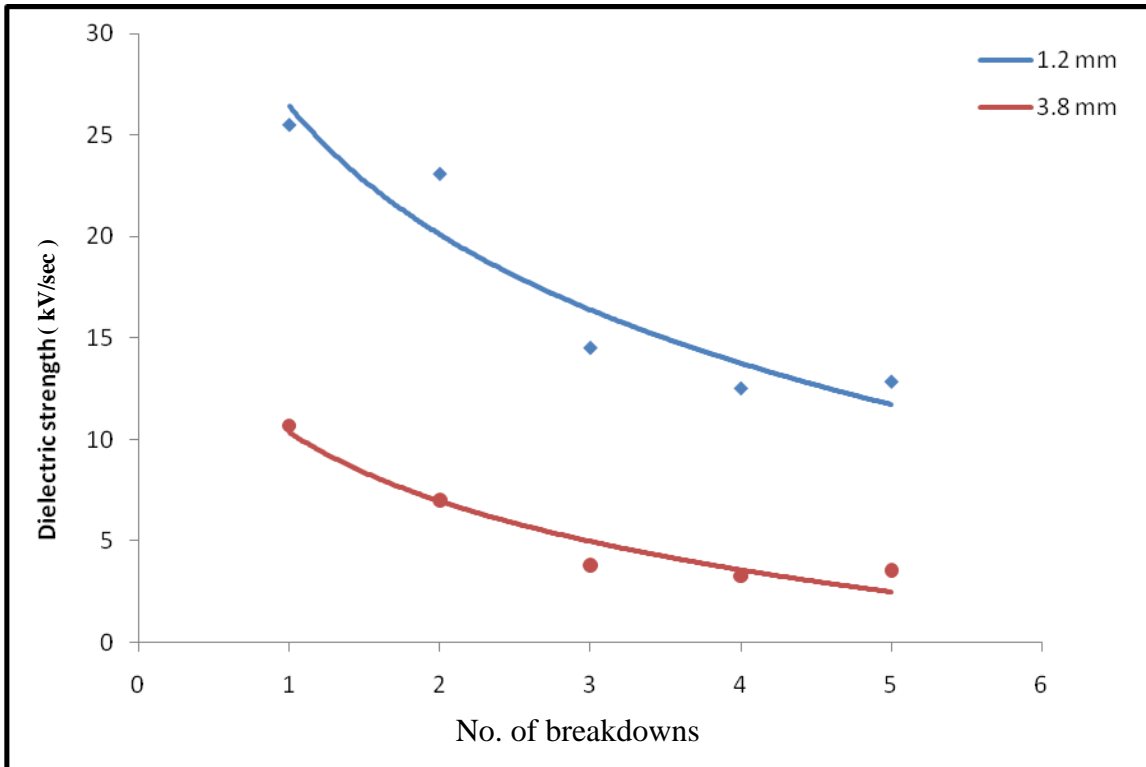


Fig. (4-19) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% NA)

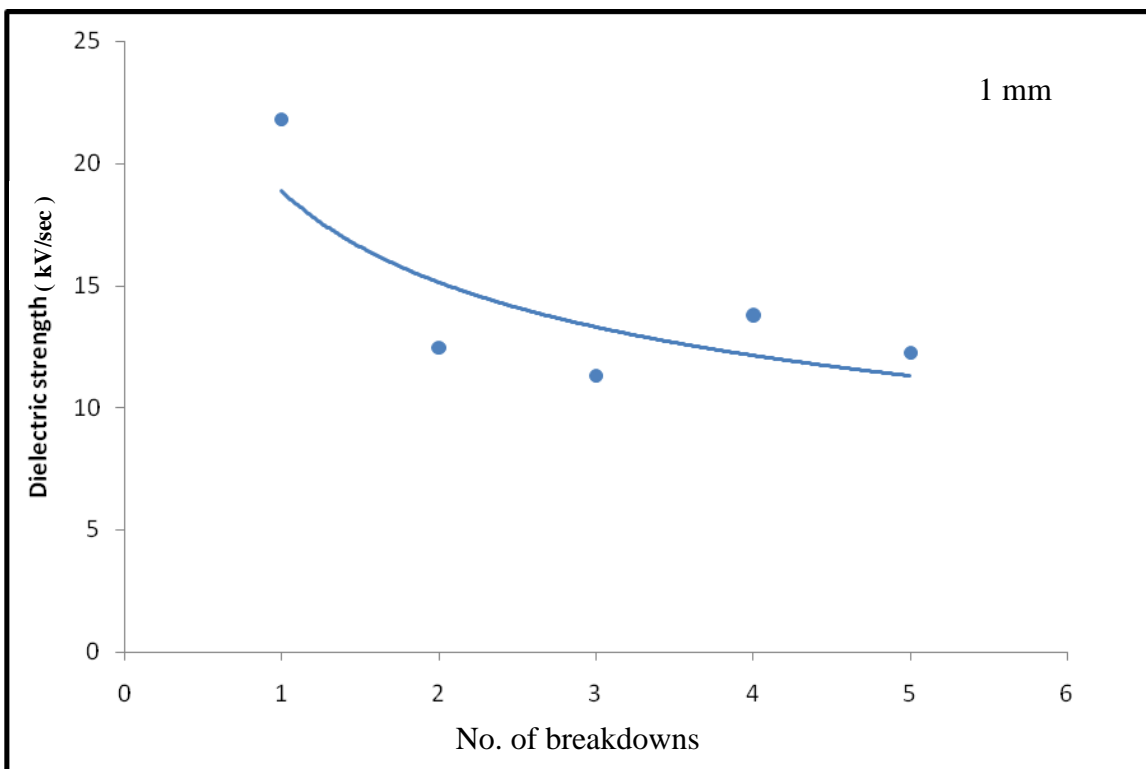


Fig. (4-20) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% MT)

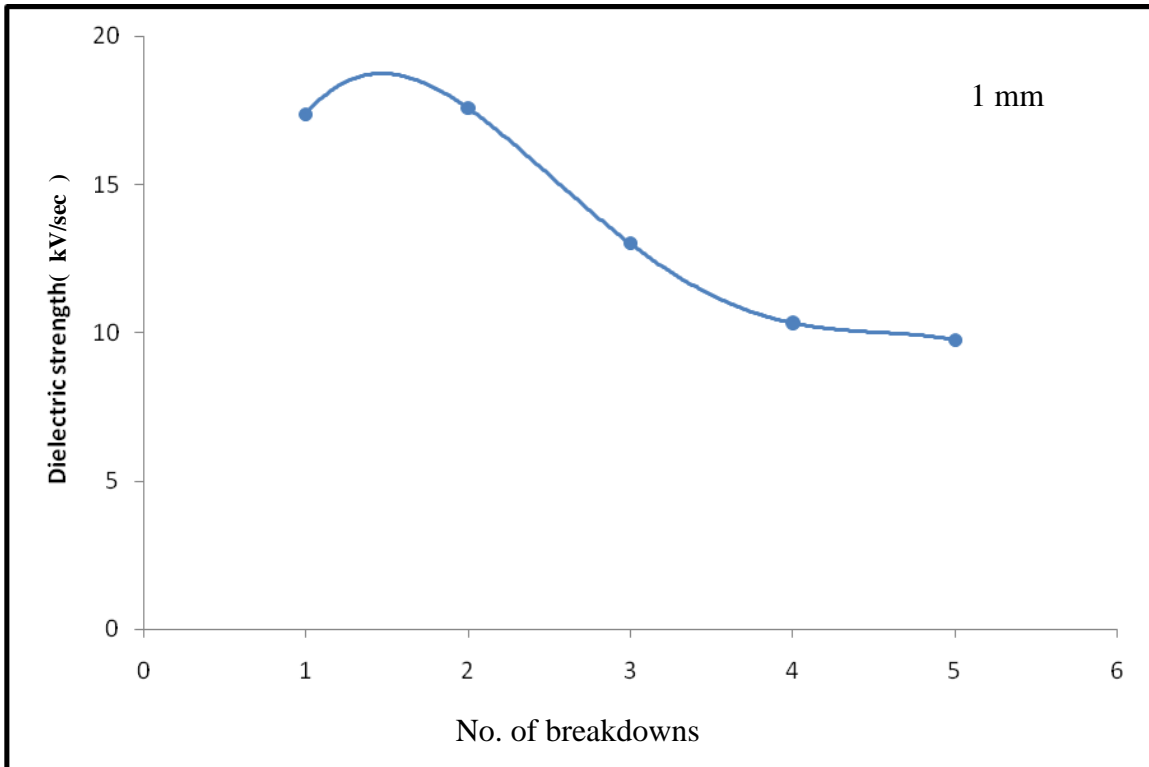


Fig. (4-21) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% MT)

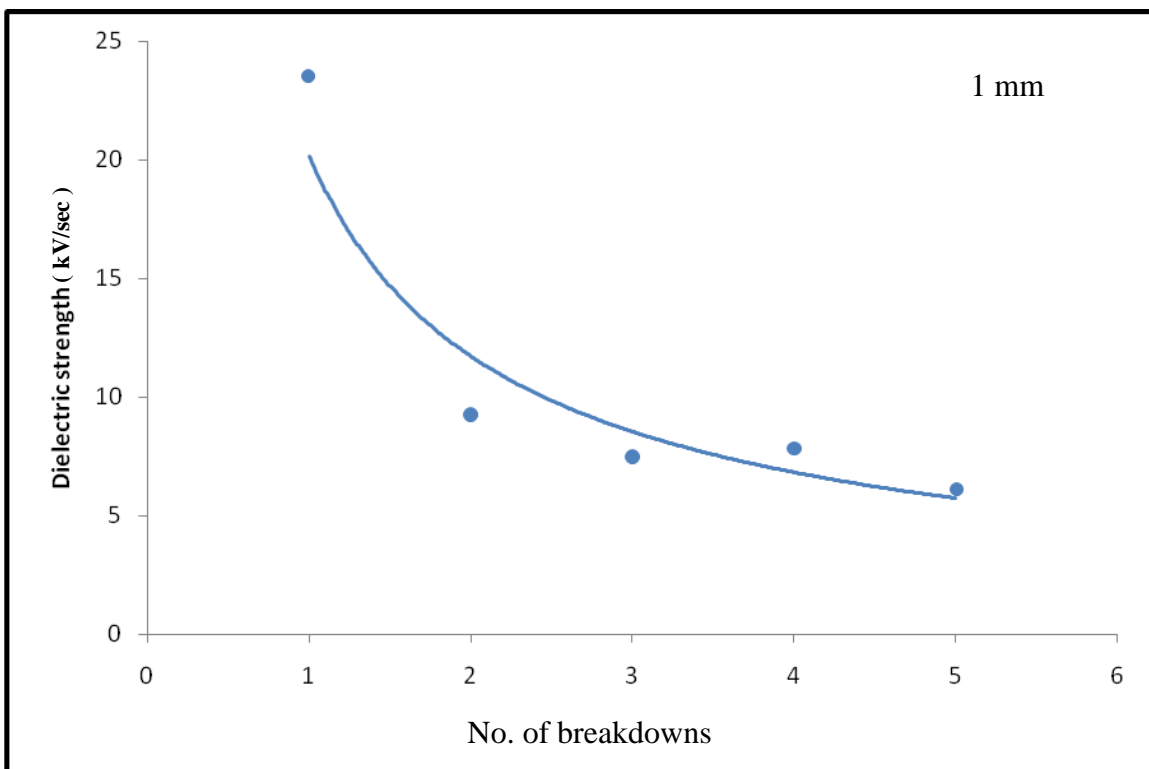


Fig. (4-22) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+1% NT)

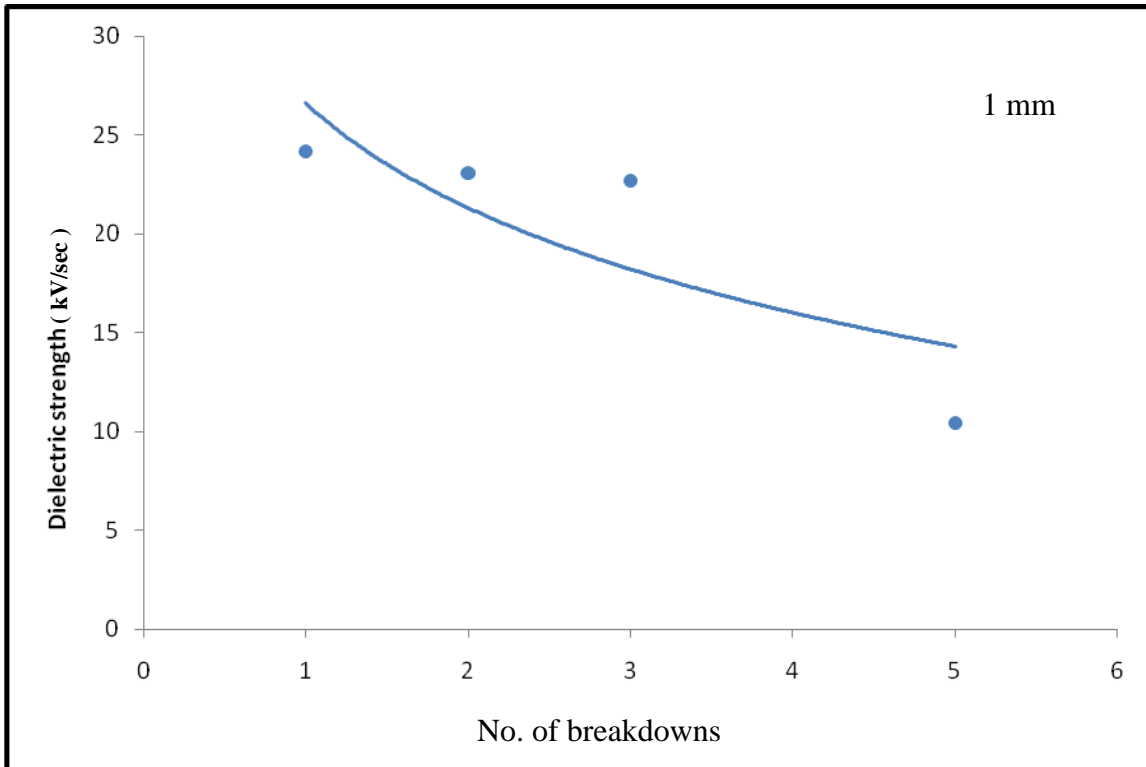


Fig. (4-23) Dielectric strength versus No. of breakdowns at (0.5 kV/sec), (UP+4% NT)

There are a number of Notes that should be taken into account, the most important is the appearance of some abnormal points in determining the values of Dielectric strength, and this falls within the rates of error allowed to as this test is one of the destructive tests, which depends heavily on the structure of material therefore, the a repetition of the results is weak in this type of tests. Also showed areas of breakdown in the form of black spots and this is proof of break the polymer chains (hydrocarbon) with conversion to carbon (the phenomenon of smut), which represents the black points. It was observed air bubbles believed to represent the hydrogen gas liberated as a result of breakdown, with continuing electric breakdown of the same point occurs oxidation of carbon and conversion of it to carbon dioxide gas leaving place as a hole in the samples.

4-3 Examination by x-ray Diffraction

Because there are some abnormal results in the dielectric strength tests by the formation new phases of a new substance or substances as a result of thermal effects of voltage on the material where there is electric breakdown caused this anomaly in the dielectric strength testing, so we use the x-ray test for the diagnosis of materials where we focus the rays beam on the points of electric breakdown accurately, we found the region where there is a electric breakdown after the examination that there was no change in phases of the materials constituting of the sample and the absence of new material after testing. As was expected before the test because the conditions of preparation of ceramic materials or change in phases need time and high temperatures. Interrelated factors were behind of anomalous behavior in electrical tests that we have already refer to it, but the reason behind decreasing of the density is convert small part of alumina to amorphous. the following figures (4-24), (4-25), (4-26), (4-27), show that:

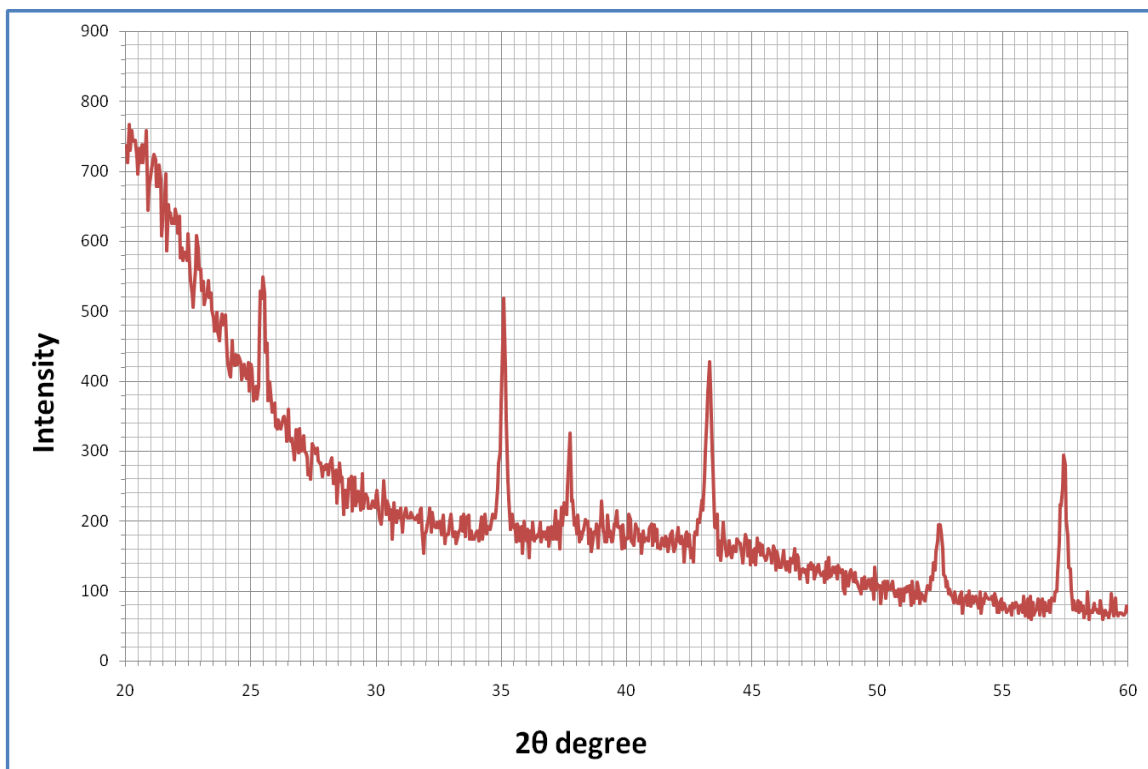


Fig. (4-24) XRD pattern for the (UP+4%NA) before the electric breakdown

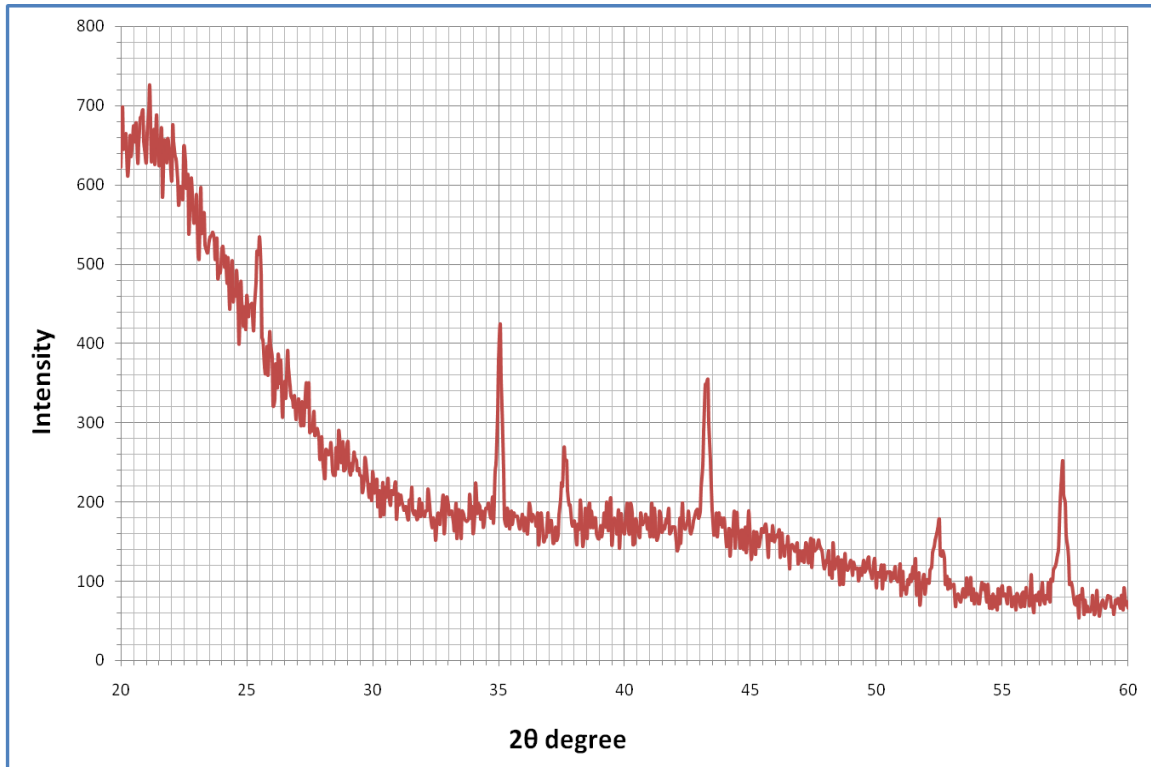


Fig. (4-25) XRD pattern for the (UP+4%NA) after the electric breakdown

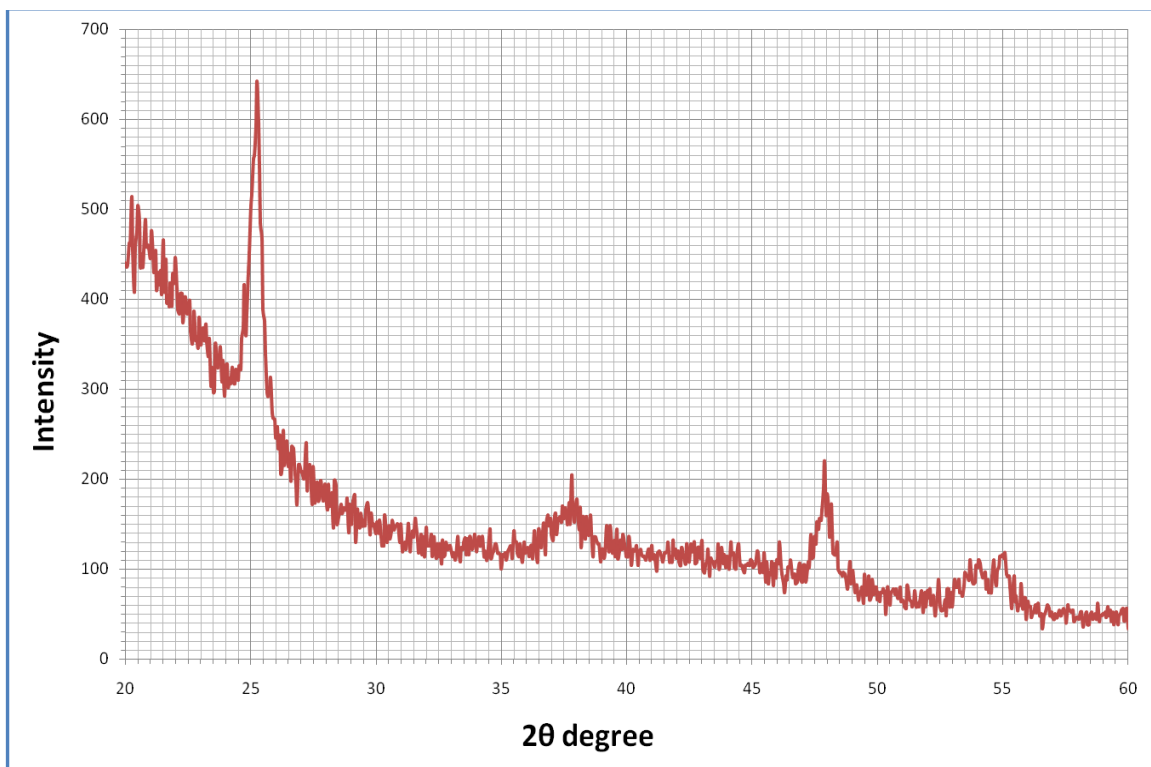


Fig. (4-26) XRD pattern for the (UP+4%NT) before the electric breakdown

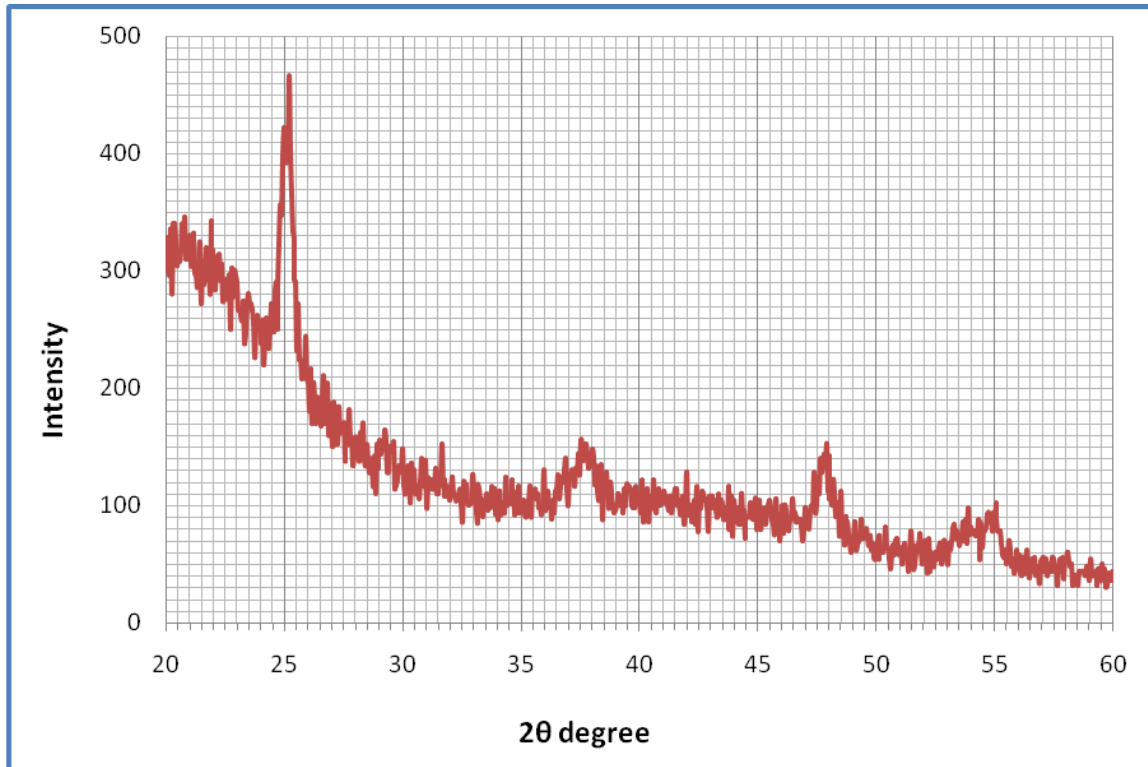


Fig. (4-27) XRD pattern for the (UP+4%NT) after the electric breakdown

4.4 Optical Microscope Pictures

The images taken for the electric breakdown points by using optical microscopy have shown that the sample coated in the electric breakdown area as a result of destroying of polymeric chains to unsaturated polyester (UP), and the formation of micro cracks as a result of electric breakdown which extends directly to the point of electric breakdown. The optical microscope pictures show that there is micro cracks were larger and more sinuosity and distortion of the micro samples, This is because the great convergence of nanoparticles, diffusing, dispersal, high homogeneity and high stable distribution in all directions, that nanoparitcles enjoyed and the most important distinguish of nano reinforcement. Either the micro reinforcement suffers from weaknesses in the diffuse and The homogeneity and that because of the large mass and size, which often tend to agglomeration in the bottom. As is well known, a different degree of particles agglomeration of a substance to another cause a change its

characteristics. the figures: (4-28), (4-29), (4-30), (4-31), (4-32), (4-33), (4-34), (4-35), (4-36), (4-37), (4-38), (4-39), (4-40), (4-41).

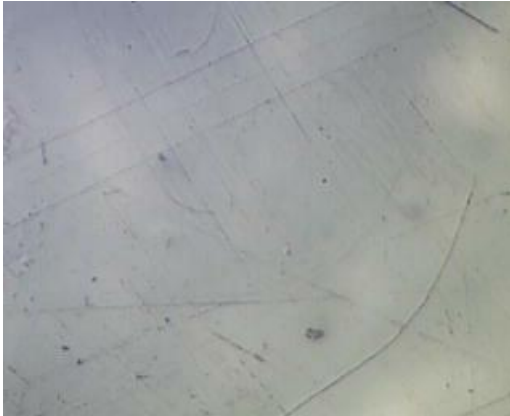


Fig.(4-28)sample before
breakdown(UP)



Fig.(4-29) sample after
breakdown(UP)

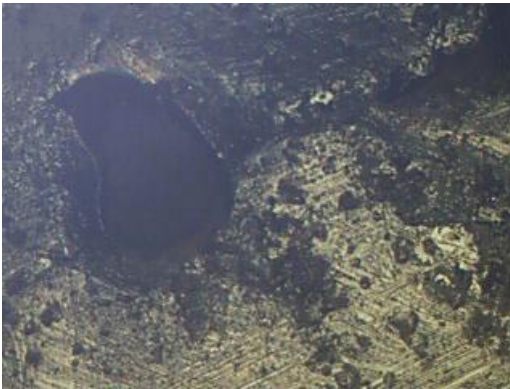


Fig.(4-30) sample after
breakdown(UP+1%MA)



Fig.(4-31) sample after
breakdown(UP+1%MA)

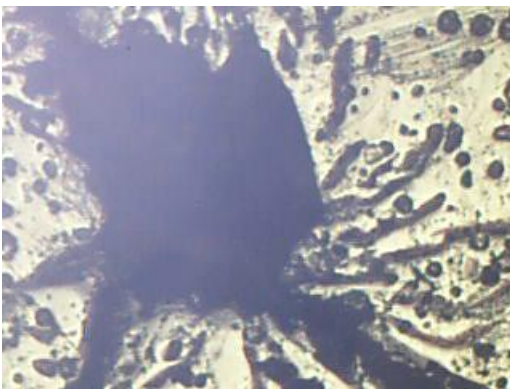


Fig.(4-32) sample after
breakdown(UP+1%MA)

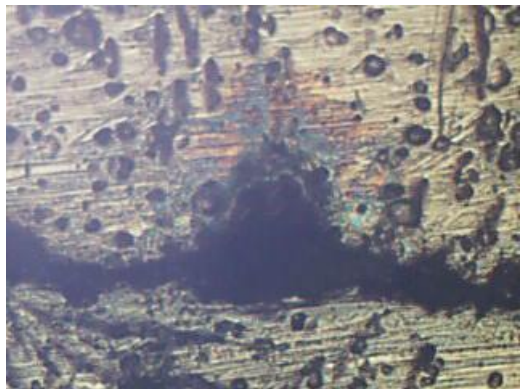


Fig.(4-33) sample after
breakdown(UP+2%MA)

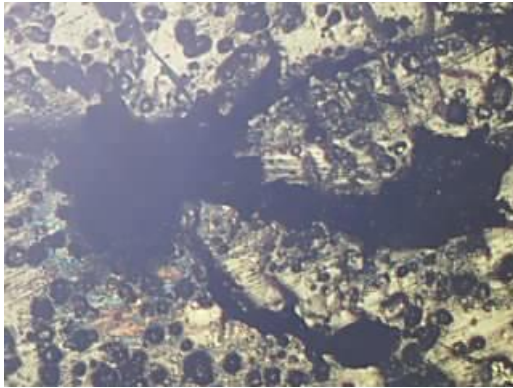


Fig.(4-34) sample after breakdown(UP+3%MA)

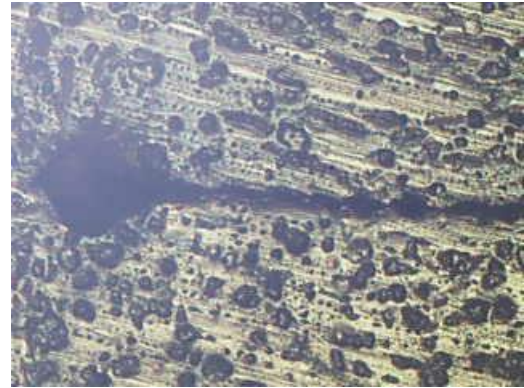


Fig.(4-35) sample after breakdown(UP+4%MA)



Fig.(4-36) sample after breakdown(UP+1%NA)

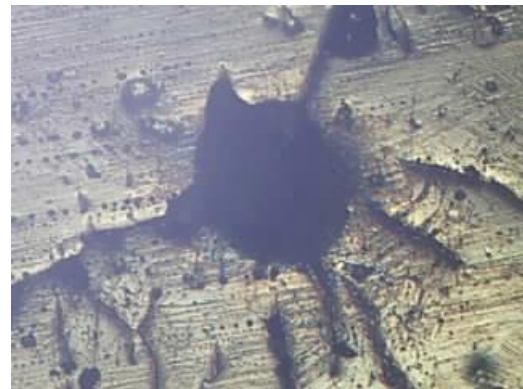


Fig.(4-37) sample after breakdown(UP+1%NA)

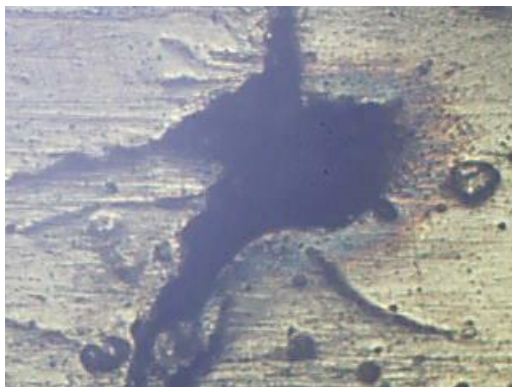


Fig.(4-38) sample after breakdown(UP+2%MA)



Fig.(4-39) sample after breakdown(UP+3%MA)

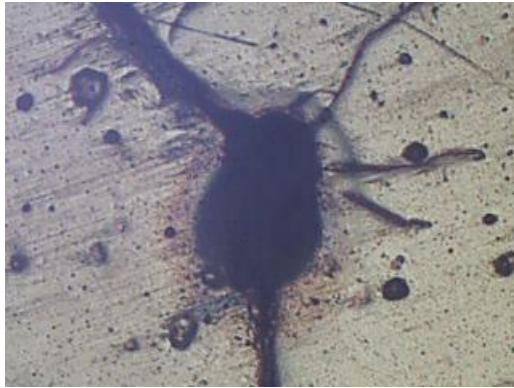


Fig.(4-40) sample after
breakdown(UP+4%NA)



Fig.(4-41) sample after
breakdown(UP+4%NA)

4.5 The Effect of Additives Rates on the Dielectric Constant

The figures (4-42), (4-43) show behavior of dielectric constant with the rates of addition at room temperature and range of frequencies ($25049.75-5 \times 10^6$) Hz for polymer composite samples (UP + micro alumina), (UP+ nano alumina), (UP + micro titania) and (UP + nano titania), the results showed increase in the values of dielectric constant with increase in the alumina and titania additions, The reason for that may be due to:

1. The contribution of fillings (alumina and titania) to raise the values of dielectric constant of the polymer composite because it has dielectric constant values higher than the matrix material (Unsaturated Polyester).
2. Dielectric constant increases with the proportion of alumina and titania added because of the increased in number of dipoles per unit volume which mean increase in the number polarized dipoles, which oriented with the effect of electric field.
3. The reason for the increase in dielectric constant is the appearance of Interfacial polarization mainly with addition of fillings to unsaturated polyester as the values of dielectric constant increased, for all the ratios prepared.

4. Increase the porosity of polymer composite samples especially when the unsaturated polyester is the matrix material which lead to increased in the polarization of the growing spatial charges.
5. For the high dielectric constant values when add titania fillings due to the high values of dielectric constant of titania higher than the values of dielectric constant of alumina.
6. For the high values of dielectric constant at the nanoparticles fillers are higher than the values of dielectric constant in the microparticles fillers are attributed high diffusion, stable, specific surface area and arrange distribution in all directions that enjoyed by the nanoparticles in the matrix material (unsaturated polyester) and the high homogeneity for reinforcement of samples with nanoparticles and the great convergence between nanoparticles that the most important what distinguishes reinforcement by nanoparticles. Reinforcement microparticles samples are often suffers from weaknesses in the diffuse and heterogeneity due to their large particle size, which often tend to agglomeration in the lower layer of the sample because of gravity of the microparticles that are larger than of the nanoparticles because of the large mass, especially if the matrix material is a liquid, as in the unsaturated polyester. as is known, a different degree of particles gathering of a substance to another cause the change in characteristics of the polymer composite samples.

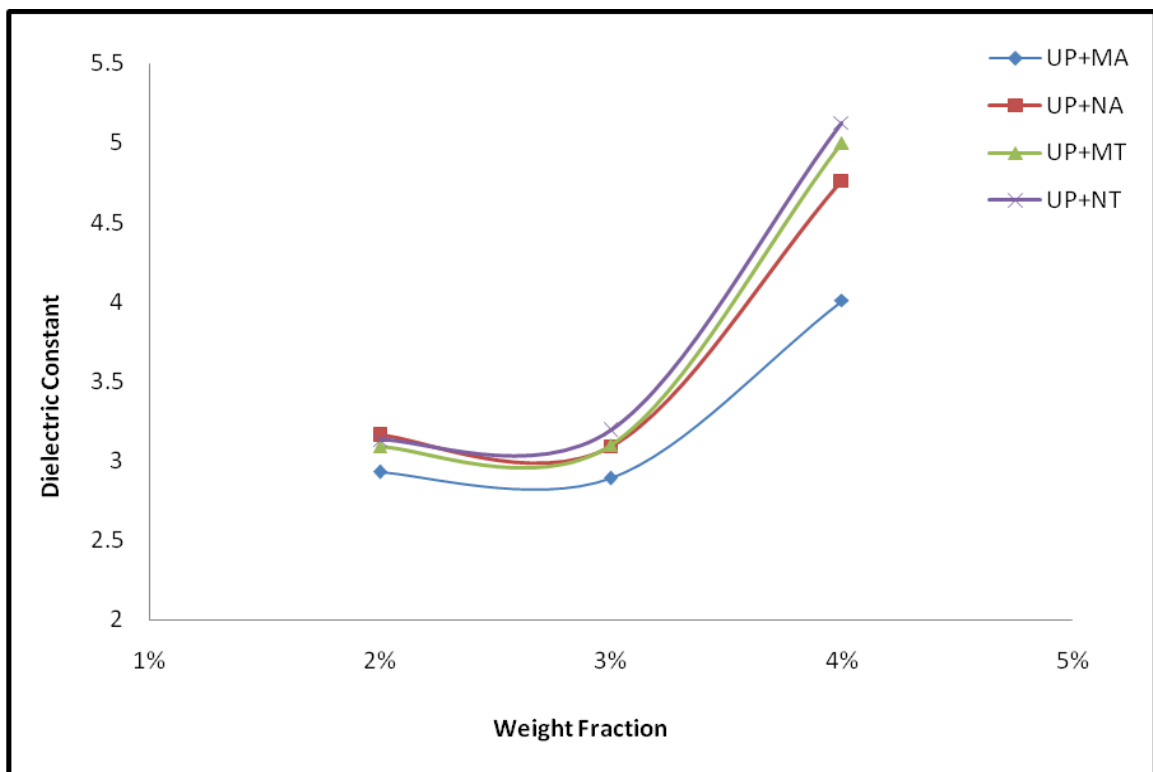


Fig. (4-42) Dielectric constant versus weight fraction at (5×10^6 Hz), (for all additives)

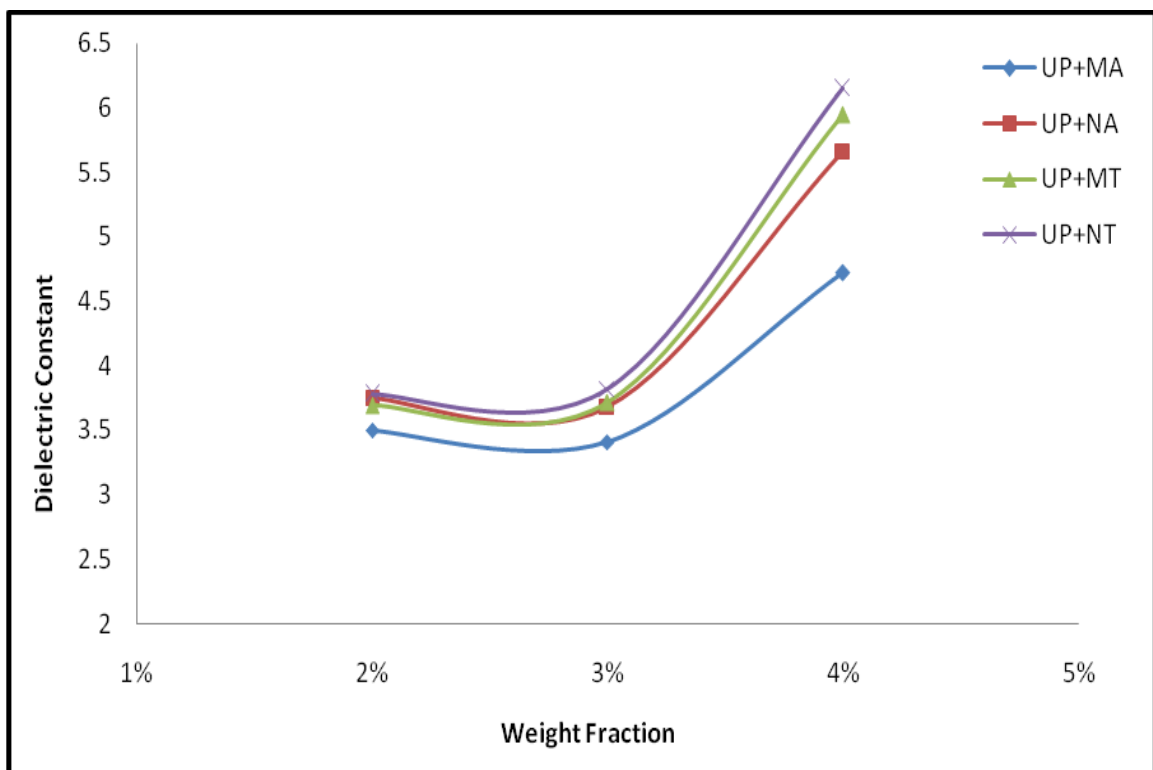


Fig.(4-43) Dielectric constant versus weight fraction at (25049.75 Hz), (for all additives)

4-6 The Effect of Frequency on the Dielectric Constant

Figures (4-44), (4-45), (4-46) show behavior of dielectric constant with frequency at room temperature and range of frequencies ($25049.75-5 \times 10^6$) Hz for polymer composite samples (UP + micro alumina), (UP + nano alumina), (UP + micro titania) and (UP + nano titania), The results show that values of Dielectric constant at low frequencies is high relatively because of the effect of interfacial, orientation and ionic polarization where its effect appears fully. The orient polar group is slow relatively and that the decrease in the values of dielectric constant with increasing the frequency of each weight fractions caused by retardation of these polarizations are sequential not keep pace with the change in the direction of the electric field followed by retardation of the orientation polarization and ionic polarization to keep pace with the change in the electric field, respectively (retardation of oriented dipoles), leading consequently to the decrease in the values of dielectric constant with increasing frequency, and this was normal behavior as in other insulators.

In other words, if the frequency has risen significantly, the moments will be unable to follow up the electric field and this effect leads to the dispersion of dielectric constant with increasing in frequency and this phenomenon is known as the dispersion of insulator material. Usually, Orientation polarization in the direction of the electric field at low or small frequencies, which it is neglected when the frequency is very high, this is referred to Dielectric relaxation We note from these figures that we cannot get areas in which the electric field is stable and doesn't follow dielectric constant with the frequency, perhaps this is due to the lack of frequencies lower than 20 Hz, so that we can have access to stable zone.

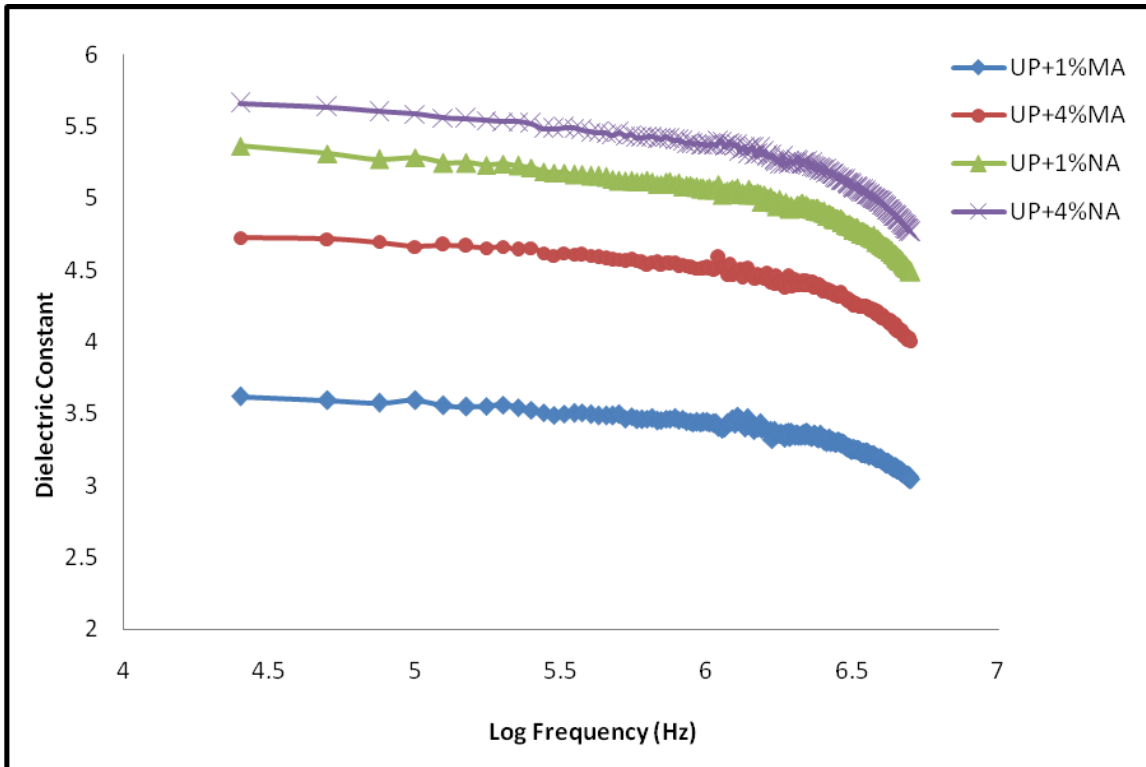


Fig. (4-44) Dielectric constant versus frequency for alumina additives

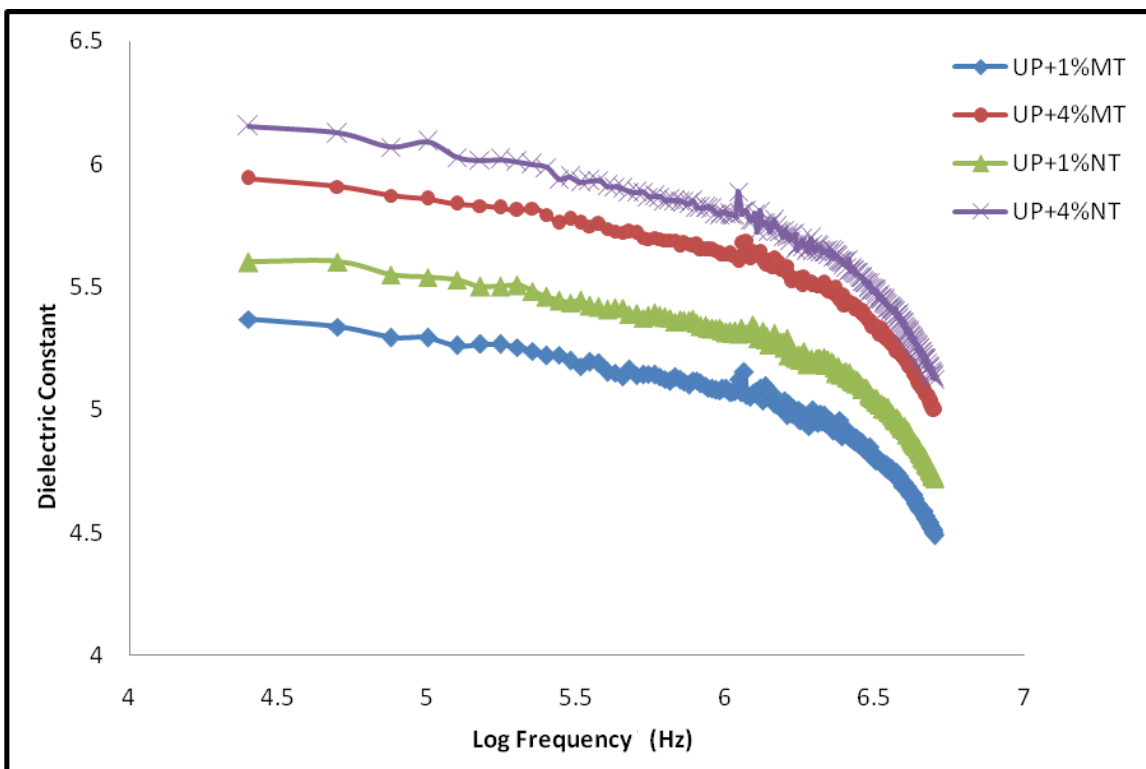


Fig. (4-45) Dielectric constant versus frequency to titania additives

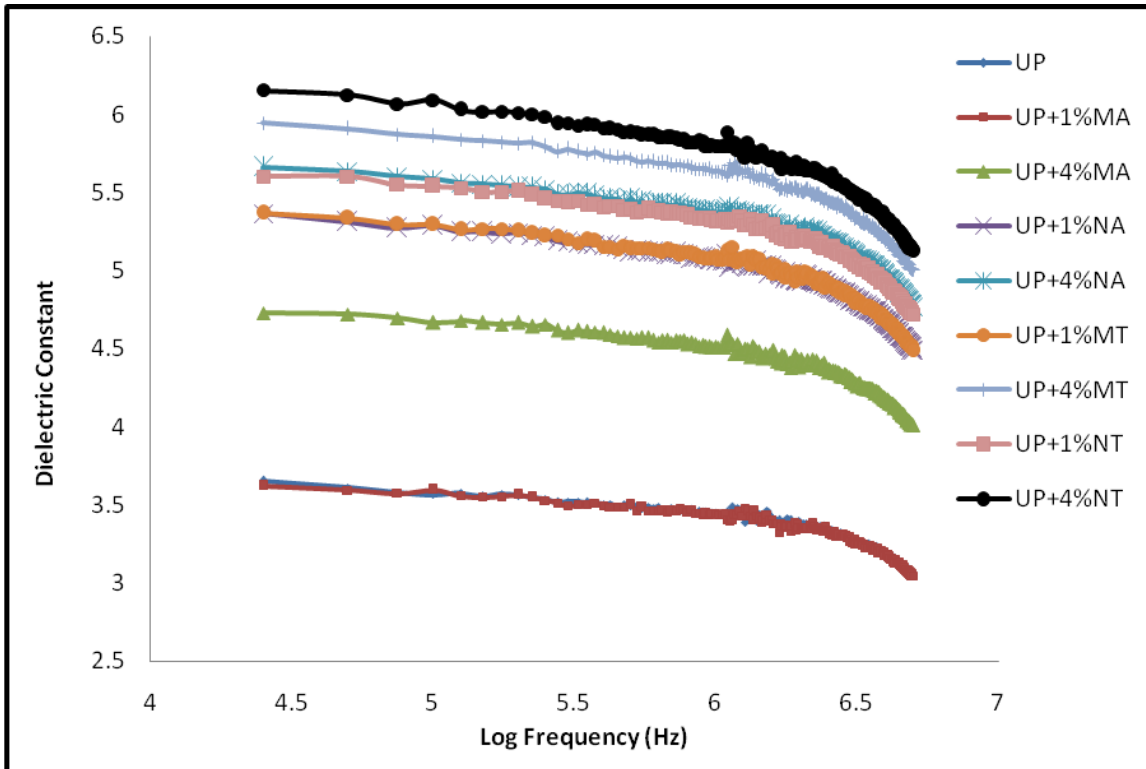


Fig. (4-46) Dielectric constant versus frequency for all additives

4-7 Effect of Frequency on the Dispersion Factor

The figures (4-47), (4-48), (4-49), (4-50), (4-51), (4-52), (4-53), (4-54), (4-55), show the relation of dispersion factor ($\tan\delta$) and frequency at room temperature and at range of frequencies ($25049.75-5 \times 10^6$)Hz for polymer composite samples (UP + micro alumina), (UP + nano alumina), (UP + micro titania) and (UP + nano titania), The results show similar in behavior of dispersion factor ($\tan\delta$) and frequency for all samples and it is the oscillation in values of dispersion factor ($\tan\delta$) with frequency, where values of dispersion factor ($\tan\delta$) increased gradually with increasing frequency and reach high value (maximum value) and then dispersion factor ($\tan\delta$) begin decreasing gradually. The change in dispersion factor ($\tan\delta$) values return to change of dispersion factor to incubator polymer material as in the equation below [131] :

$$\tan \delta = \frac{\epsilon_r'}{\epsilon_r''} = \frac{(\epsilon_s - \epsilon_\infty)\omega\tau}{(\epsilon_s + \epsilon_\infty\omega^2\tau^2)} + \frac{\sigma}{\omega}$$

Where: ϵ_{∞} :is the maximum value of the electric permittivity, ϵ_s :is the minimum value of the electric permittivity, ω : is angular frequency, τ : is relaxation time, ϵ'_r : is Real Dielectric constant, and ϵ''_r : is Imaginary dielectric constant, σ : is alternating electrical conductivity.

It can be observed from the second term ($\frac{\sigma}{\omega}$) of the equation above, that the increase in the value of the dispersion factor ($\tan\delta$) to be closely related to the alternating electrical conductivity, which in turn depends on the number of charge carriers within the material, it's relaxing time and applied electric field frequency, when temperature is constant. The reason for the increase in the alternating electrical conductivity when you add the filler is the appearance of charges between the interfaces surfaces (between filling material and incubator material (UP)) which increases with increasing the filler content to a maximum value with increasing frequency[132]. In this case, the mechanism of jumping is the controlling mechanism,so that when the jumping frequency is approximately equal to the frequency of the applied electric field, so we get peak value of dispersion factor ($\tan\delta$), and when continue increasing frequency, it leads to the vanishing term ($\frac{\sigma}{\omega}$) and becomes not influential, causing decreasing and vanishing of the value of the dispersion factor ($\tan\delta$). We further note that when increasing the content of the fillings ratio for each samples, the relaxation peaks shift towards low frequencies and this behavior in this polymer is similar to what observed by a number of other researchers when they studied Dielectric properties of different polymers. one can take advantage of this behavior in determining the relaxation time of materials [131-133].

There is another reason for the change in dispersion factor ($\tan\delta$) with frequency due to the dipoles absorb energy of the electric field in order to overcome the resistance of the viscous material that surrounds them during rotation. This absorbed energy reduces the transition charge carriers between the edges of capacitor with increasing of the frequency and dipoles which need high energy in order to get relaxation and this cause a decreased of dispersion factor

($\tan\delta$). The increase in dispersion factor ($\tan\delta$) at certain frequencies is due to get relaxation all dipoles by absorb of part of the energy while the other part is used for the transfer of charge carriers. also may get the case of resonance when consensus applying electric field frequency with the natural frequency of dipoles which gets high loss.

In these composites may be get multiple resonance cases because theses composites consist of different particles for different elements so there is resonance frequency for each element and this is what we expected and founded during this research .

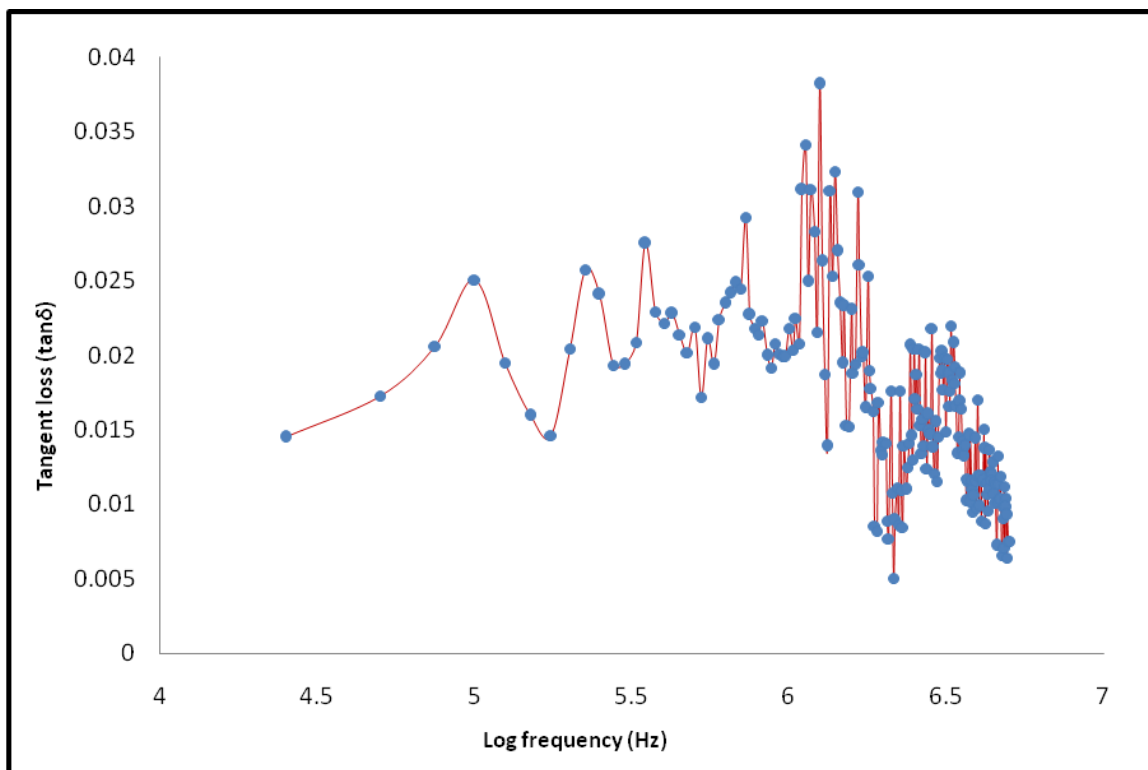


Fig. (4-47) Tangent loss versus frequency (UP)

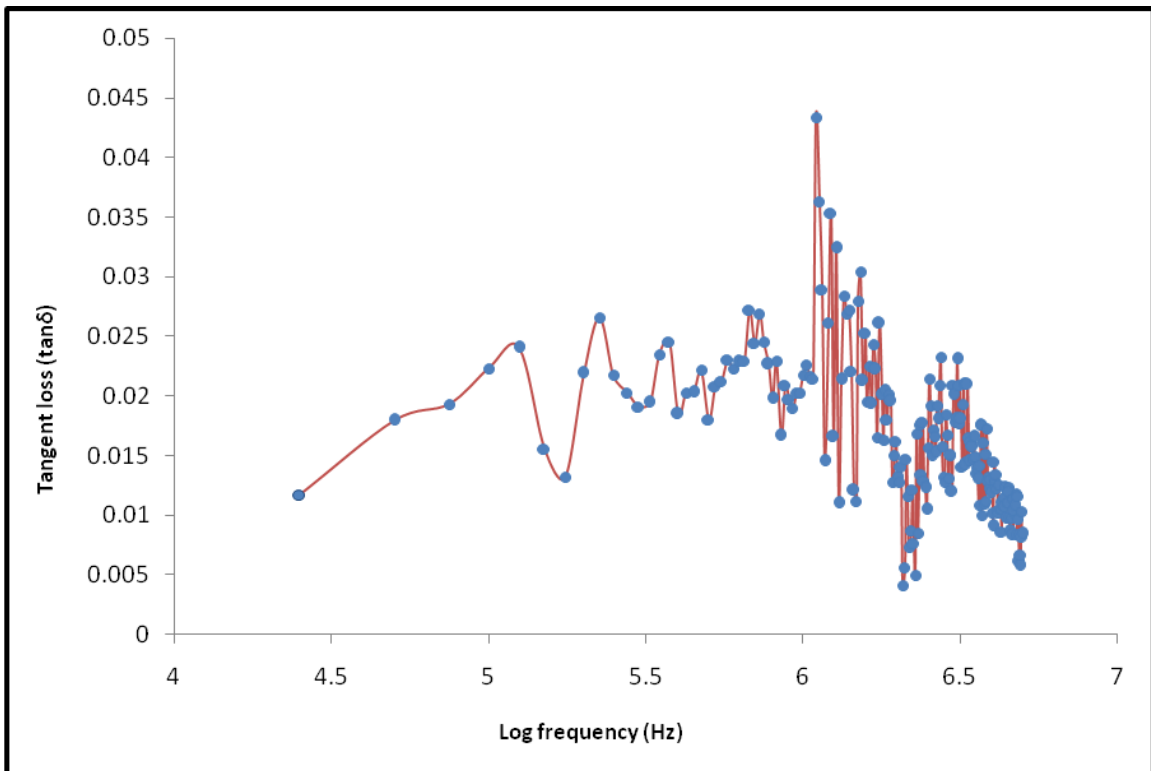


Fig. (4-48) Tangent loss versus frequency (UP+1%MA)

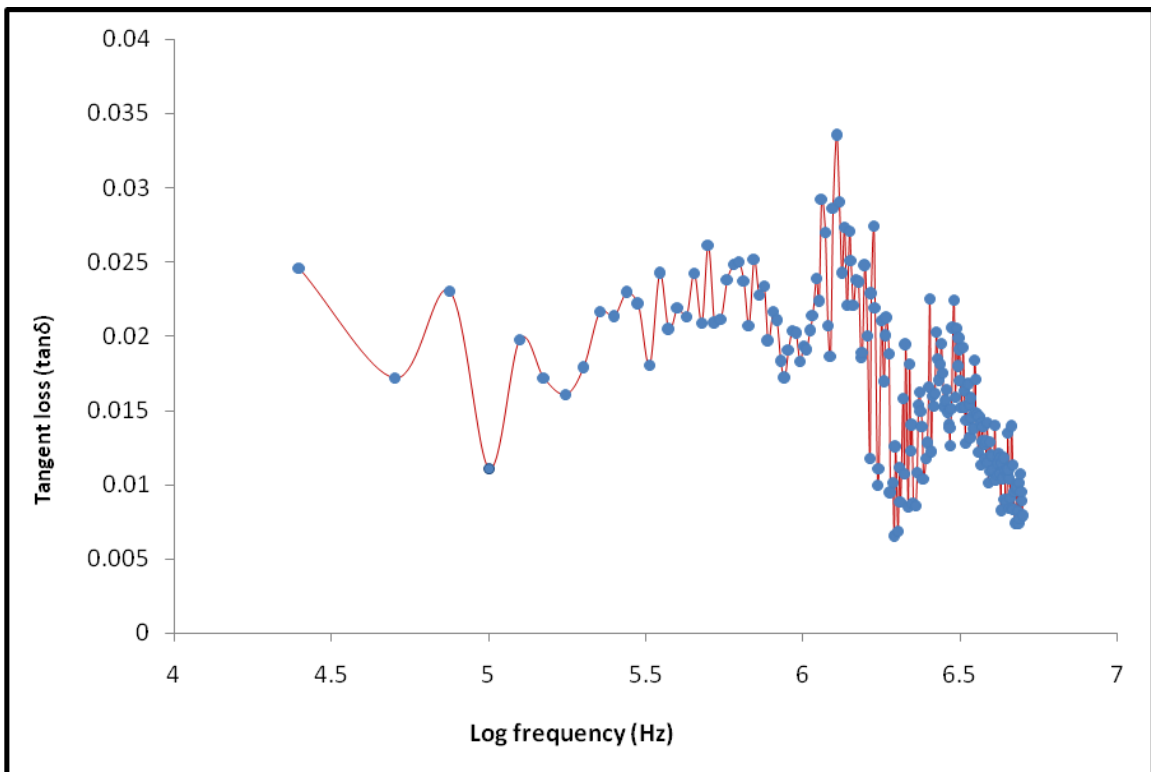


Fig. (4-49) Tangent loss versus frequency (UP+4%MA)

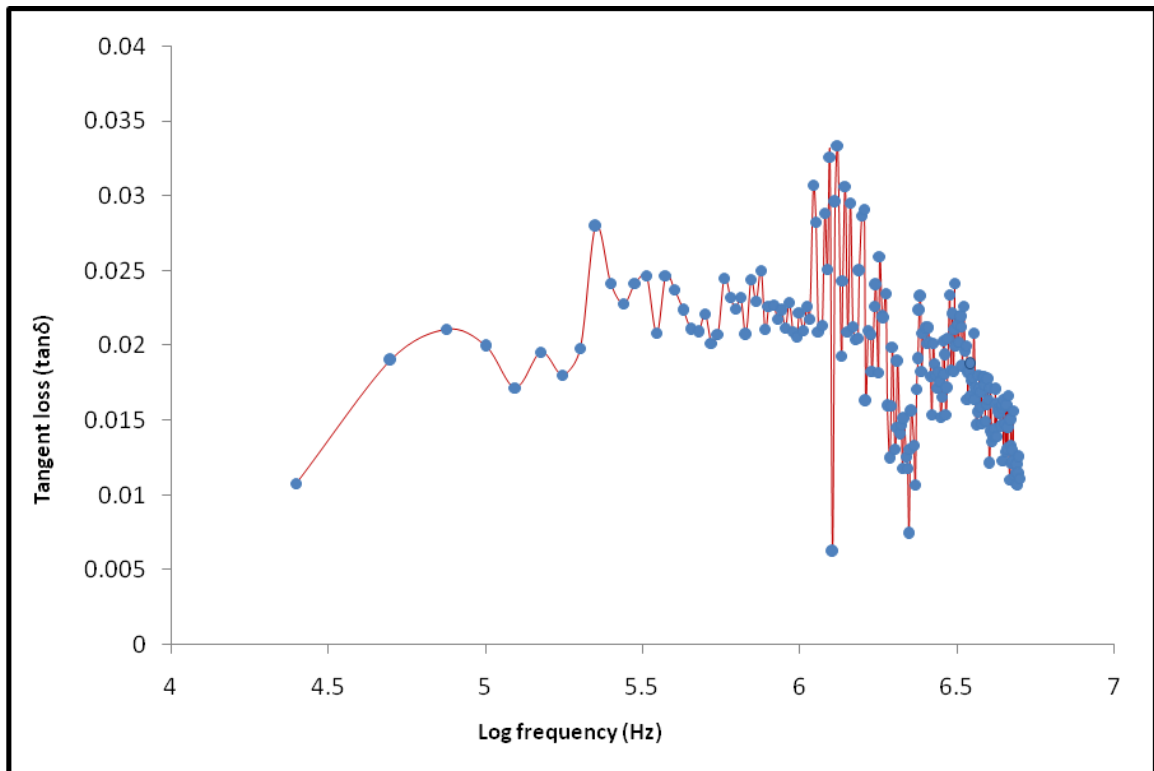


Fig. (4-50) Tangent loss versus frequency (UP+1% NA)

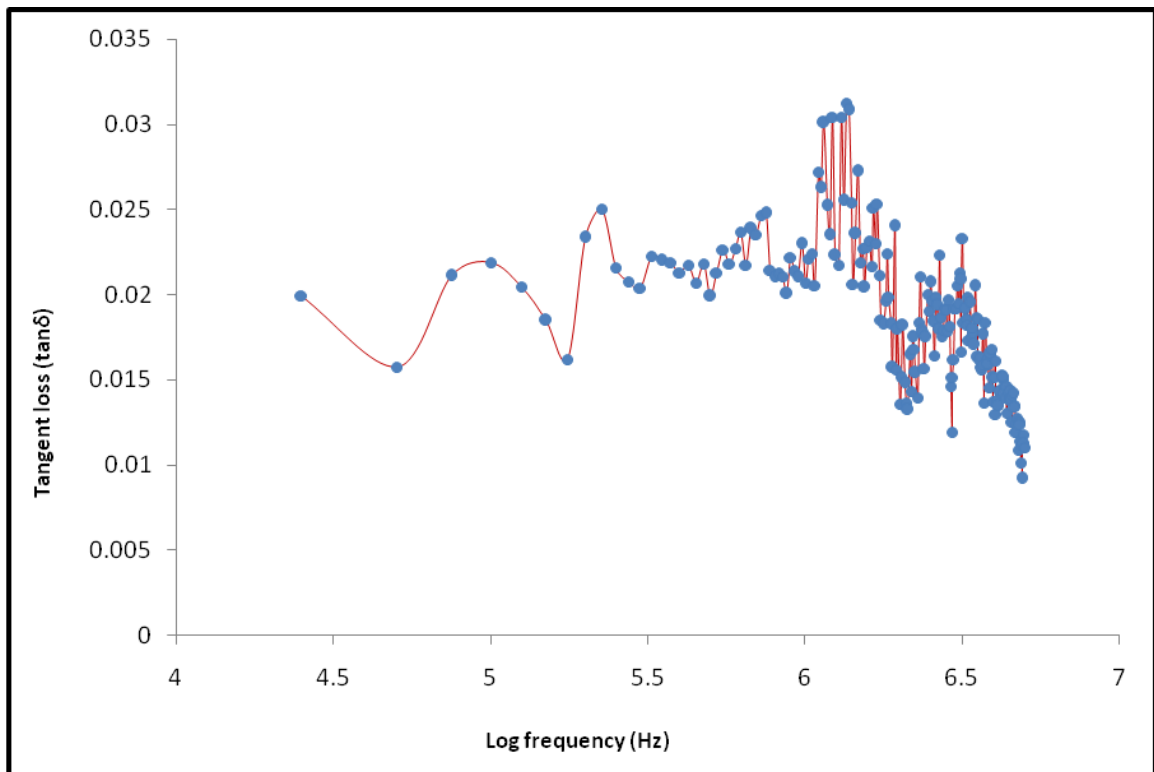


Fig.(4-51) Tangent loss versus frequency (UP+4% NA)

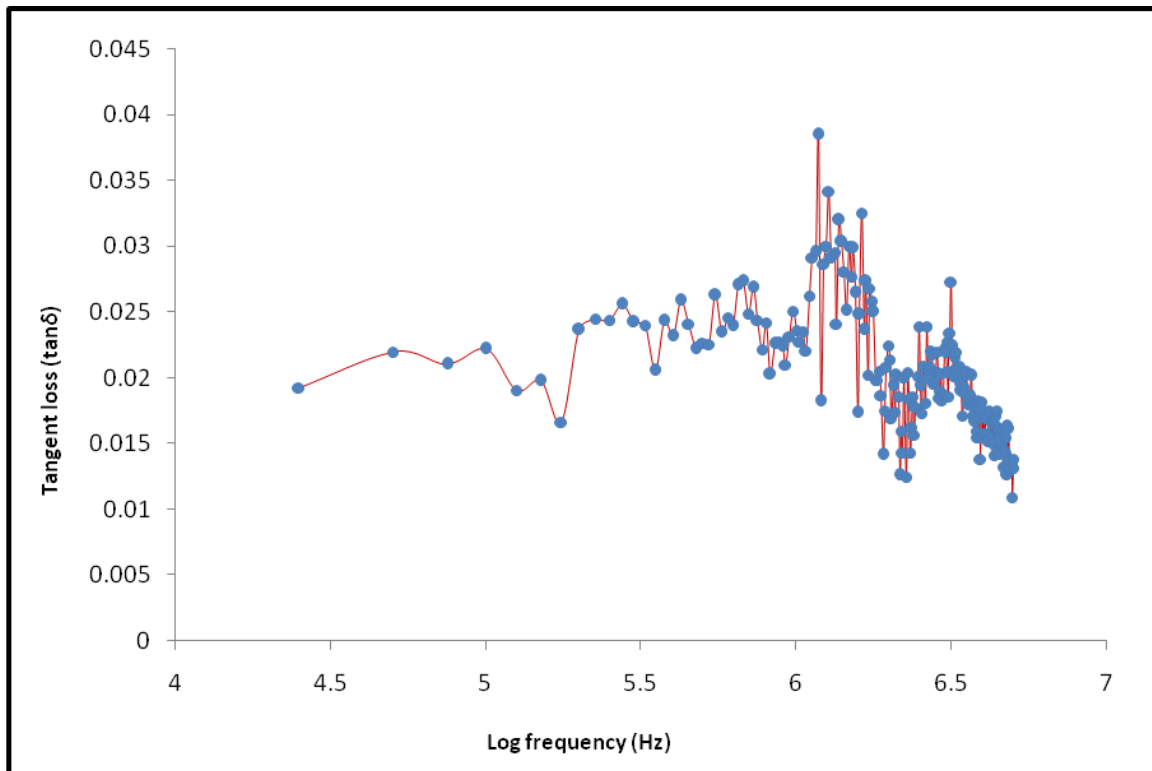


Fig. (4-52) Tangent loss versus frequency (UP+1%MT)

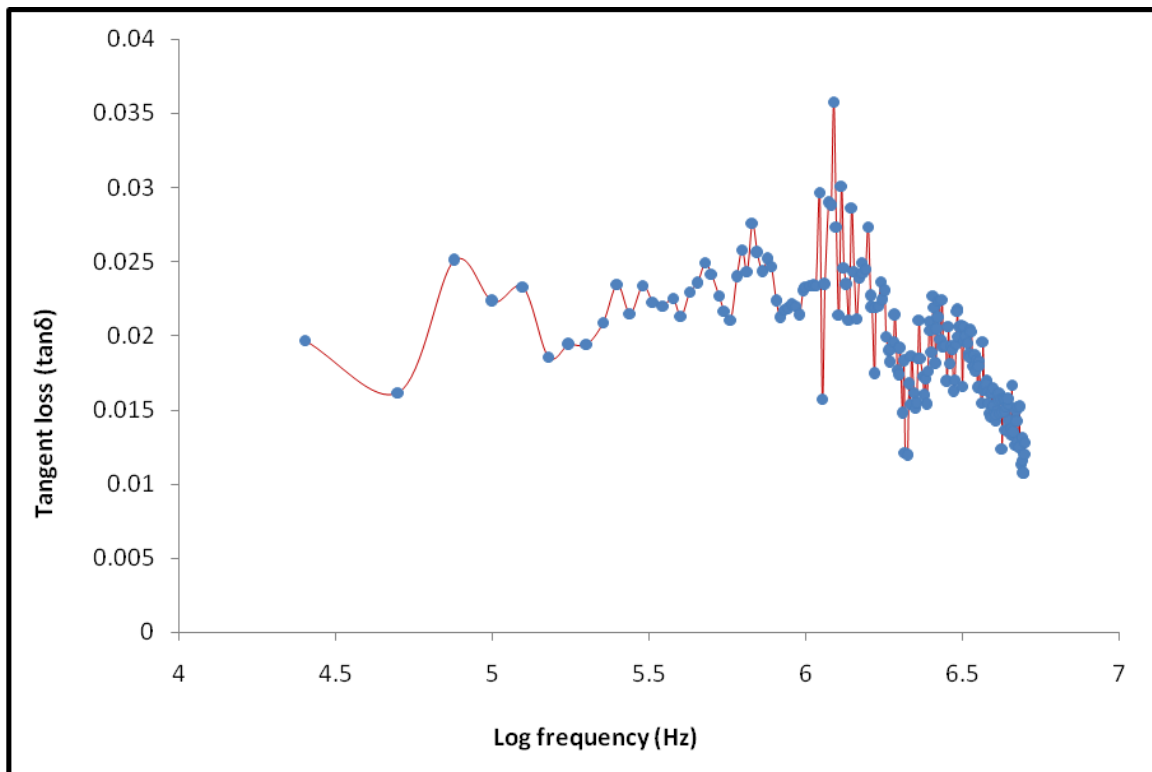


Fig. (4-53) Tangent loss versus frequency (UP+4%MT)

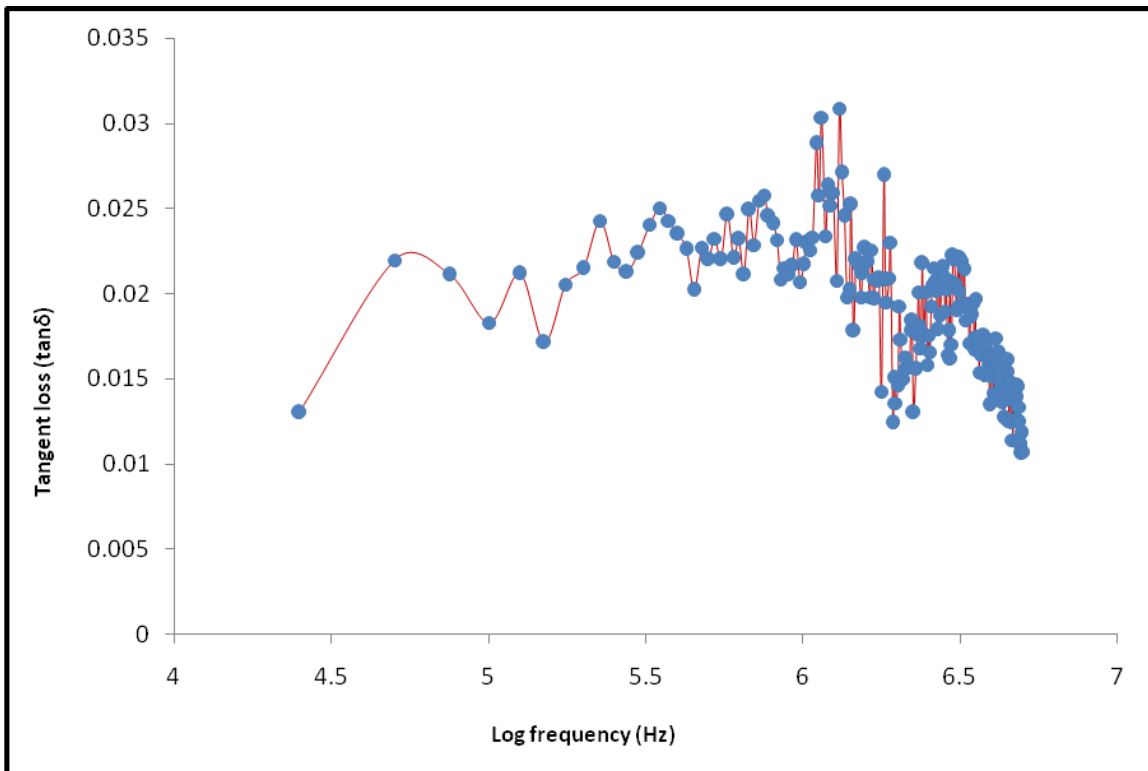


Fig. (4-54) Tangent loss versus frequency (UP+1% NT)

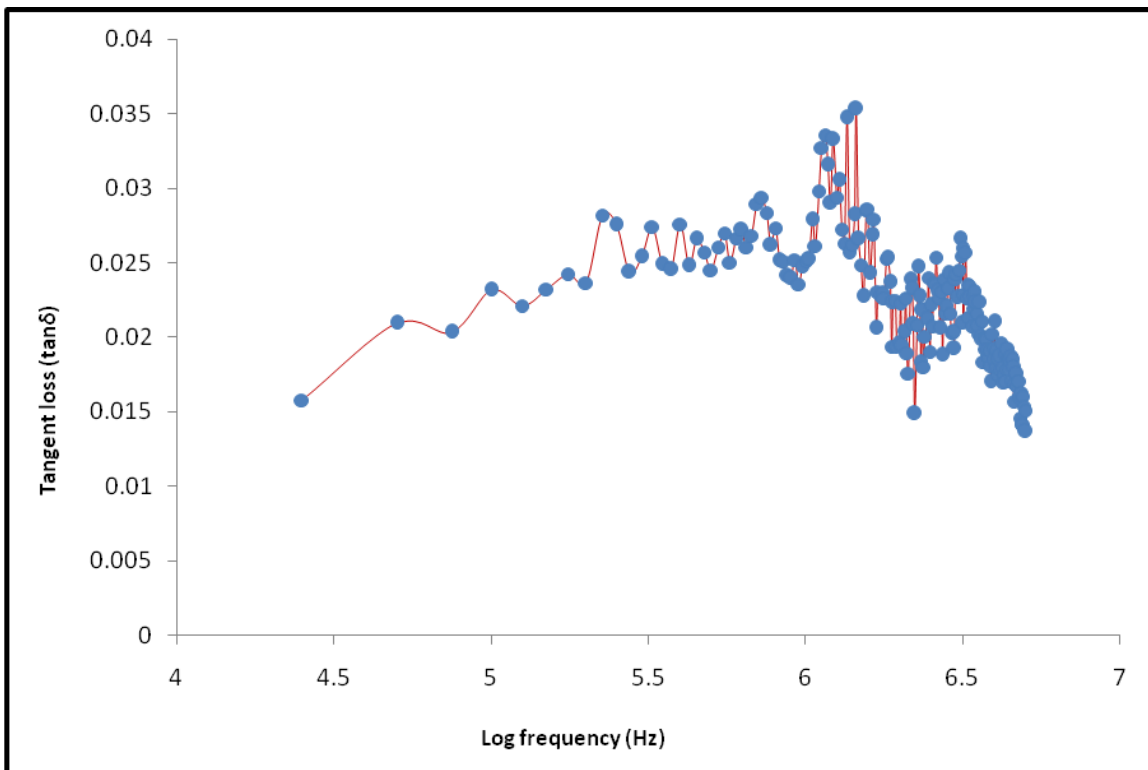


Fig. (4-55) Tangent loss versus frequency (UP+4% NT)

5.1 Conclusions

The findings of the study lead to the following conclusions:

1. The dielectric strength decrease when the ceramic materials added (Alumina and Titania) to the matrix material (Unsaturated Polyester), and the composite (UP + titania) has dielectric strength less than the composite (UP + alumina).
2. The dielectric strength of both Composites (UP + alumina) and (UP + titania) decrease with the increase in thickness, its prefer in determining the values of the dielectric strength to use a small thickness because of the lack of proportionality and non-linear in change of dielectric strength with thickness.
3. The dielectric strength increase with the increase of average elevating voltage for both Composites (UP + alumina) and (UP + titania), and the appearance of a decrease in dielectric strength with low elevating averages which means that there is electrothermal effect occurs within the insulator material must be taken into consideration during the selecting of a dielectric strength under an operating conditions.
4. The dielectric strength decrease with the number of breakdowns for both Composites (UP + alumina) and (UP + titania), with the appearance of black areas in the test areas which is coaled of the breakdown point as a result of carbon convert to carbon dioxide.
5. Variation occurs during measuring the dielectric strength, and this means that the material composition, its phases and the defects effect on the behavior of electric spark inside the insulator material with repeating manner causes inaccuracy in the measurements and it applied statistically over group of tests out come.
6. The values of dielectric constant for both Composites (UP + alumina) and (UP + titania) increases with increasing the proportion of ceramic additive and be higher for composite (UP + titania), and the values of dielectric constant decreases with increasing frequency, while the values of the loss tangent increases with increase frequencies to reach the highest value at

relaxation frequency, then its value begins to decrease gradually at frequencies greater than relaxation frequency.

7. Generally, x- ray examinations showed for both Composites (UP + Al₂O₃) and (UP + TiO₂) no change in phases in the electric breakdown region for the constituent materials of the sample with the absence of new material create after the test.
8. Excluding the use of polymeric composite from the service after obtaining of the electric breakdown because of the extremely low dielectric strength after the first round of the electric breakdown directly.
9. It can be consider that a mechanism of the dielectric strength testing as one of the methods in which it examines the homogeneity and the dispersal of reinforcement material in the composite material.
10. The possibility of taking the advantage of prepared polymer composites reinforced by (alumina and titania) in many electronic applications depend on its measured properties.

5.2 Recommendations

Based on the findings of this study, the following recommendations are put forward:

1. Use of other oxides such as (ZrO₂, SiO₂, etc.) as reinforcement material with unsaturated polyester or with other polymers such as PVC and Epoxy.
2. The preparing of thin films for the same composites (UP + Alumina) and (UP + Titania) and studying the properties of their insulating.
3. Studying the mechanical and optical properties of the composites (UP + Alumina) and (UP + Titania) in order to get the advantage and take advantage in modern scientific applications.
4. Studying the Effect of electrical resistivity, activation energy and alternating, direct electrical conductivity for the composites (UP + alumina) and (UP + titania).

5. Studying mechanical tests of the samples after the electric breakdown to determine the effect of the electric breakdown on the material strength and studying the Electromechanical influence.
6. Studying the effect of (frequency, humidity, temperature, type of poles) on the dielectric strength and dielectric constant for the preparing composites.

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Abstract

This research includes studying the effect of adding ceramic materials which represents by aluminum dioxide (alumina- Al_2O_3) and titanium dioxide (titania- TiO_2), with different particle sizes ranging between micro size and nano size as dispersion to unsaturated polyester (UP) as a matrix material and also the studying some affecting factors on the dielectric strength, dielectric constant, dispersion factor (loss tangent), and X-ray examination of the composite material. Reinforcement ceramic materials (alumina and titania) with weight fraction (1%, 2%, 3%, 4%) was added to unsaturated polyester, and prepared by Hand lay-Up Molding and the thicknesses ranged between (1-4) mm. Generally, the results of tests showed increases dielectric strength with the increases in proportion of additive ceramic, and the values of dielectric strength of the composite (UP + TiO_2) was less than the values of dielectric strength of the composite (UP + Al_2O_3) This is due to high dielectric constant possession for titanium dioxide, with dielectric loss factor higher than alumina compared with other insulator materials and also it appear that the dielectric strength decreases with increasing dielectric loss factor.

The results showed for both Composite (UP + Al_2O_3) and (UP + TiO_2) respectively, a decrease in the dielectric strength with thickness increasing, and increasing in the dielectric strength with the increase in the average elevating voltage. The effect of the number of applying breakdown voltage on the dielectric strength for both Composite has decreased dielectric strength clearly after the first round. The results showed for both Composite (UP + Al_2O_3) and (UP + TiO_2), respectively, an it was shown also the increase in the values of dielectric constant with increasing of the proportion

of additive ceramic (alumina + titania) and a decrease in the values of dielectric constant with increasing frequency, either tangent loss was observed that its value increases with increasing frequency to reach to the highest value at the relaxation frequency, and then its values start to decrease gradually at frequencies greater than relaxation frequency. The x-ray examinations made clear to both Composite (UP + Al₂O₃) and (UP + TiO₂) on the whole, in the region in which the electric breakdown occurs any change in the phases for the constituent materials of the sample does not seem and there is no new material has been appear after the test. 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 (UP) destroyed, and there is appearance of microscopic cracks as a result of electric breakdown extends directly from the point of electric breakdown.