

Republic of Iraq Ministry of Higher Education and Scientific Research University of Diyala College of Science Department of Physics



Evaluation of the Physical Properties of Fibers Reinforced Hybrid Nanocomposites and Their Applications

A Thesis

Submitted to the Council of College of Science University of Diyala in Partial Fulfillment of Requirements for the Degree of Doctor of Philosophy (Ph.D.) in Physics

By

Maher Nadher Abdullah

M. Sc. in Physics (2015)

Supervised by

Prof. Dr. Sabah A. Salman Asst. Prof. Dr. **Mustafa A. Rajab**

1442 A.H.

2020 A.D.

بِسْم اللهِ الرَّحْمَنِ الرَّحِيم

المَنْ عَامَنُوا مِنْكُمُ اللَّذِينَ ءَامَنُوا مِنْكُمْ وَٱلَّذِينَ أُوتُوا الْعِلْمَ دَرَجَتِ وَٱللهُ بِمَا تَعْمَلُونَ خَبِيرُ

صَدَق الله الْعَظِيْم

(سورة المجادلة /الآية ١١)..



To my family: My **Father's** spirit, **mother** and all **brothers** respect. My wife (**Jehan**) My Love. My Sons:

> Rami, Rania and Abdullah. To my colleagues especially.

> > Maher



Praise be to ALLAH for all things

I am so grateful to everybody who has given me the support that I needed to complete this work.

My deep appreciation is extended to my supervisors *Prof. Dr. Sabah A. Salman* and *Assist. Prof. Dr. Mustafa A. Rajab* for their keen involvement and competent guidance in every phase of this work. I am indebted to them for their suggestions and valuable remarks.

Special thank are extended to the Dean of the College of Science and to head of Physics Department Prof. *Dr. Ziad T. Khudair* and all the Staff of the Department of Physics for their assistance and special thanks to the Dean of the College of Science, *Prof. Dr. Tahseen H. Mubarak*.

My greatest indebtedness goes to my wife (*Jehan*) for her endless support.



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 doctor of philosophy (Ph.D.) in Physics.

Signature, Sab

Name: **Dr. Sabah A. Salman** Title: Professor Date:15/3/2020

Signature,

Name: Dr. Mustafa A. Rajab

Title: Asst. Professor Date:15/3/2020

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

Signature, 3lou

Name: Dr. Ziad T. Khodair

Title: Professor

Head of the Department of Physics

Date: 15/3 / 2020



We certify that we have read this thesis entitled "Evaluation of the Physical Properties of Fibers Reinforced Hybrid Nanocomposites and Their Applications" and, as an examining committee, we examined the student (Maher Nadher Abdullah) on its content and in what is related to it, and that in our opinion it meets the standard of a thesis for the degree of Doctor of Philosophy in Physics.

N.A. Bakr Signature Name: Prof. Dr. Nabeel A. Bakr Address: University of Diyala Date: 20/9/2020 Chairman M Signature Signature Name: Prof. Dr. Tagreed Muslim Marush Name: Prof. Dr. Farah. T. M. Noori Address: University of Baghdad Address: University of Baghdad Date: 20/9/2020 Date: 20 / 9 / 2020 Member Member Signature *A* Signature Name: Prof. Dr. Ziad T. Khodair Name: Prof. Dr. Tariq J. Alwan Address: University of Diyala Address: Mustansiriyah University Date: 20 / 9 / 2020 Date: 20 / 9 / 2020 Member Member Signature Signature Name: Prof. Dr. Sabah A. Salman Name: Assist. Prof. Dr. Mustafa A. Rajab Address: University of Diyala Address: Middle Technical University Date: 20 / 9 / 2020 Date: 20 /9 / 2020 Supervisor Supervisor

Approved by the Council of the College of Science.

(The Dean)

Signature:

Name: Prof. Dr. Tahseen H. Mubarak Date: 24/9/2020



I certify that the thesis entitled "Evaluation of the Physical Properties of Fibers Reinforced Hybrid Nanocomposites and Their Applications" presented by (Maher Nadher Abdullah), has been evaluated scientifically, therefore, it is suitable for debate be examination committee.

Signature: C. L. Kalhim

Name: Bahjat Bahlol Kadhim

Title: Professor

Address: Mustansiriyah University

Date: 4 / 5 / 2020



I certify that the thesis entitled " Evaluation of the Physical Properties of Fibers Reinforced Hybrid Nanocomposites and Their Applications" presented by (Maher Nadher Abdullah), has been corrected linguistically, therefore, it is suitable for debate be examination committee.

Signature: Alfca

Name: Alyaa M. Abdelhameed Title: Asst. Professor Address: University of Diyala Date: 2 / 5 / 2020



- M. A. Rajab, S. A. Salman and M. N. Abdullah, "Absorption of Composite Material Epoxy-Phenol Formaldehyde Hybrid Blend", Journal of Research in Mechanical Engineering, Vol. 4, No. 1, pp. 18-22, (2018).
- M. A. Rajab, S. A. Salman and M. N. Abdullah, "Mechanical Behavior of Epoxy-Phenol Formaldehyde Hybrid Blend ", International Research Journal of Innovations in Engineering and Technology, Vol. 2, No. 6, pp. 1-4, (2018).
- **3.** M. N. Abdullah, S. A. Salman and M. A. Rajab, "Using Epoxy-Phenol Formaldehyde Hybrid Blend as an Alternative to the Materials Used in the Manufacture of The Oil Pan in The Vehicle's Internal Combustion Engine", Indian Journal of Natural Sciences, Vol. 9, No. 52, pp. 18-22, (2019).
- 4. M. A. Rajab, M. N. Abdullah and S. A. Salman, "Electrical Behavior of Hybrid Blend Reinforced by Fibers with Different Mixing Ratios", International Journal of Research-Granthaalayah, Vol. 7, No. 7, pp. 93-101, (2019).
- 5. M. A. Rajab, S. A. Salman and M. N. Abdullah, "Effect of Nanoparticles and Fibers Types on Hybrid Blend Composite Materials Behavior of Epoxy and Phenol-Formaldehyde", International Journal of Nanoelectronics and Materials, Vol. 13, No. 1, pp. 91-100, (2020).



Epoxy and phenol formaldehyde were mixed with different weight fractions (0,5,10,15,20,30.40 and 50%) and the optimum blend was obtained mechanical and physical tests was 95% ER/5% PF. The second step reinforced by ZrO and MgO nanoparticles with weight fraction of (1%). The third step reinforced by GF, CF and KF fibers. Finally reinforced by ZrO and MgO nanoparticles with weight fraction (1%) and GF, KF and CF fibers with weight fraction of (1%) to study the effect mechanical properties (tensile, bending, impact and hardness testes) and physical properties (thermal conductivity, dielectrical, water absorption tests).

The mechanical properties of EP/PF in the tensile strength test increase with increasing of PF concentration, and at (5%) weight fraction obtained the maximum ratio in improve the tensile strength about (1.2%). Tensile strength of EP/PF/MgO increased about (12.3%) and at ER/PF/CF was the large increasing in tensile strength about (936.3%), the best result of tensile strength was at ER/PF/MgO/CF than ER/PF.

Results of bending strength and bending modulus tests of ER/PF was the best at composite 90%ER/10%PF in stress value, and when increased the weight fraction the stress value became lower, and at composite ER/PF/ZrO stress value increase about (300%) than 95% ER/5% PF, and when reinforced ER/PF with fibers the best result at ER/PF/CF compare to ER/PF/GF and ER/PF/KF. Reinforced ER/PF by fibers and nanoparticles obtained a stress value three times highest especially at ER/PF/MgO/CF compare to ER/PF reinforced by fibers or nanoparticles.



We notice increased impact strength with increased ER/PF weight fracture and take the optimal result at 95% ER/5% PF, After that the impact strength decreases with the increase in the weight fracture, and then the addition of MgO and ZrO nanoparticles led to an increase in the impact strength and the best result was at ER/PF/MgO by a large difference to 95% ER/5% PF, on the other hand, it is found that the ER/PF/KF increases the impact strength than 95% ER/5% PF. We notice an increase in the impact strength value of 95% ER/5% PF when it is reinforced by MgO and ZrO nanoparticles with different fibers, where ER/PF/MgO/KF has the highest value of the impact strength.

The optimum hardness test result was obtained at 95%ER/5%PF to reinforced by nanoparticles and fibers, and the best result was ER/PF/ MgO, ER /PF/MgO/GF and ER/PF/MgO/GF.

Thermal conductivity behavior of ER/PF exhibited the optimum result at 95%ER/5%PF and thermal conductivity decreases at 80%ER/20%PF. When reinforced ER/PF by nanoparticles we have high thermal conductivity at ER/PF/ZrO and low thermal conductivity at ER/PF/MgO. Addition fibers in ER/PF we obtained highest thermal conductivity at ER/PF/KF and lowest Thermal conductivity at ER/PF/CF. Reinforces ER/PF by fibers and nanoparticles led to obtain highest value of thermal conductivity at ER/PF/MgO/KF and ER/PF/ZrO/KF.

The high dielectric constant and dielectric loss value was at 80% ER/20% PF and the high electrical conductivity value was at 95%ER/5%PF, and when reinforced ER/PF by fibers obtained higher value of dielectric



constant, dielectric loss and A.C. electrical conductivity at ER/PF/CF than ER/PF/GF and ER/PF/KF, and when reinforced ER/PF by MgO and ZrO nanoparticles we obtain higher value of dielectric loss at ER/PF/ZrO than ER/PF/MgO and higher value of dielectric constant at ER/PF/MgO than ER/PF/ZrO and best value of A.C. electrical conductivity at ER/PF/MgO. Improve the dielectric properties which dielectric constant, dielectric loss and A.C. electrical conductivity when reinforced by fibers and nanoparticles especially at ER/PF/MgO/CF and ER/PF/ZrO/CF.

We notice from the water absorption tests that 80% ER/20% PF has higher water absorption and water absorption increased when reinforced ER/PF by nanoparticles ER/PF/MgO and ER/PF/ZrO. The experimental results showed that ER/PF/KF has high value of water absorption, and reinforced ER/PF by nanoparticles and fibers especially at ER/PF/ZrO/KF and ER/PF/MgO/KF led to more water absorbed.

The results of all composition materials tests were compared with the standard specifications for the plastic pipes and oil pan for internal combustion engines and their application by the finite element analysis program (FEA) is simulating practical applications using a numerical technique called the finite element method (FEM). The best results at ER/PF/Mg/CF composite were in oil pan applications and ER/PF/ Mg/GF composite in plastic pipe applications.



No.	Subject	Page
	Contents	I-III
	List of Figures	IV- VII
	List of Tables	VIII
	List of Symbols and Abbreviations	IX- X
Chapter One	Introduction and Previous Studies	1-37
1.1	Introduction	1
1.2	Composites	2
1.2.1	Matrix Composites	3
1.2.1.1	Metal Matrix Composites (MMCs)	3
1.2.1.2	Ceramic Matrix Composites (CMCs)	3-4
1.2.1.3	Carbon Carbon Composites (CCCs)	4
1.2.1.4	Polymer Matrix Composites (PMCs)	4-9
1.2.2	Based on Reinforcing Material Structure	10
1.2.2.1	Particulate Composites	11-14
1.2.2.2	Fibers Reinforced Composites	14-18
1.2.2.3	Hybrid Composite Materials	18-19
1.2.2.4	Nanoparticles	19-22
1.2.2.5	Structural of Composite Materials	22-27
1.2.3	Based on Interface in Composite Materials	27
1.2.3.1	Fibers-Matrix Interface Adhesion	27-29
1000	Factors Affecting the Properties of Polymer Matrix	20.20
1.2.3.2	Composites	29-30
1.3	Nanocomposites	30-31
1.3.1	Polymer Nanocomposites	31
1211	The Factors that Effect on Polymer Nanocomposites	20
1.3.1.1	Properties	32
1.3.2	Epoxy Nanocomposites	32
1.3.3	Hybrid Organic/Inorganic Nanocomposites	33
1.4	Literature Review	33-37
1.5	Aim of the Work	37
Chapter Two	Theoretical Part	38-62
2.1	Mechanical Properties	38
2.1.1	Fracture	38-39
2.1.1.1	Ductile Fracture	39-40
2.1.1.2	Brittle Fracture	40-41
2.1.1.3	Polymer Fracture	41-43
2.1.1.4	Nanocomposites Fracture Toughness	43-45
2.1.2	Stress-Strain Behavior	45-46
2.1.3	Three-Point Bending	47-48
2.1.4	Impact Strength	48-50
2.1.5	Hardness	50-51
2.2	Physical Properties	51
2.2.1	Electrical Properties	51
2.2.1.1	Dielectric Constant	51



No.	Subject	Page
2.2.1.2	Dielectric Polarization	51-54
2.2.1.3	Electric Polarization in Frequency Changing Electric Fields	54-56
2.2.1.4	The Influence of Frequency on Dielectric Loss	56-57
2.2.1.5	Dielectric Properties of Nanocomposites	57-58
2.2.1.6	The Influence of Nanoparticles and Interaction Zones	58
2.2.2	Thermal Properties	58
2.2.2.1	Thermal Conductivity	58-60
2.2.2.2	Thermal conductivity of polymers	61
2.2.3	Moisture Absorption	61-62
Chapter Three	Materials and Preparation Method	63-83
3.1	Introduction	63
3.2	The Raw Materials	63-67
3.3	Sample Preparation	67-69
3.4	Specimens Cutting	69-70
3.5	Mechanical Tests Samples	70
3.5.1	Tensile Test Samples	70-71
3.5.2	Bending Test Samples	72
3.5.3	Impact Test Samples	73
3.5.4	Hardness Test Samples	74
3.6	Physical Tests Samples	74
3.6.1	Thermal Conductivity Test Samples	74
3.6.2	Dielectric Test Samples	74
3.6.3	Water Absorption Test Samples	74
3.7	Technical Testing Procedures	74
3.7.1	Mechanical Tests	74
3.7.1.1	Tensile Test	74-78
3.7.1.2	Bending Test	78-79
3.7.1.3	Impact Test Equipment	79-80
3.7.1.4	Hardness Test	80
3.7.2	Physical Tests	80
3.7.2.1	Thermal Conductivity Test	80-81
3.7.2.2	Dielectrical Test	81-82
3.7.2.3	Water Absorption Test	82
3.8	The Finite Element Analysis (FEA)	83
Chapter Four	Results, Discussion and Conclusions	84-145
4.1	Introduction	84
4.2	The Mechanical and Physical Properties of ER/PF Composite	94
4.2	with Different Mass Fractions of Addition	84
4.2.1	Tensile Test	84-86
4.2.2	Bending Test	87-88
4.2.3	Impact Test	89-90
4.2.4	Hardness Test	90-91
4.2.5	Thermal Conductivity Test	92-93
4.2.6	Dielectric Test	93-95



No.	Subject	Page
4.2.7	The Water absorption test	95-96
4.3	The Mechanical and Physical Properties of Reinforcement Composite Material (ER/PF with Nanoparticles).	97
4.3.1	Tensile Test	97-98
4.3.2	Bending Test	98-99
4.3.3	Impact Test	99-100
4.3.4	Hardness Test	100-101
4.3.5	Thermal Conductivity Test	102
4.3.6	Dielectric Test	102-104
4.3.7	The Water absorption Test	105
4.4	The Mechanical and Physical Properties of Reinforcement Composite Material (ER/PF with Fibers)	105
4.4.1	Tensile Test	105-107
4.4.2	Bending Test	107-108
4.4.3	Impact Test	108-109
4.4.4	Hardness Test	109-110
4.4.5	Thermal Conductivity Test	110-111
4.4.6	Dielectric Test	111-113
4.4.7	The absorption test	113-114
4.5	The Mechanical and Physical Properties of Reinforcement Composite Material (ER/PF with Nanoparticles and Fibers)	114
4.5.1	Tensile Test	114-117
4.5.2	Bending Test	117-119
4.5.3	Impact Test	119-121
4.5.4	Hardness Test	122-124
4.5.5	Thermal Conductivity Test	124-125
4.5.6	Dielectric Test	126-129
4.5.7	The Water Absorption Test	130-131
4.6	Composite Materials Applications	131
4.6.1	Plastic pipes	131-135
4.6.1.1	The Simulation Processes	135-137
4.6.1.2	The Second Step (Analyzing the Results)	137-138
4.6.2	Oil Pan in the Internal Combustion Engine	138-141
4.6.2.1	The Simulation Processes	142-143
4.6.2.2	The Second Step (Analyzing the Results)	143-145
Chapter Five	Conclusions and Future Recommendations	146-147
5.1	Conclusions	146
5.2	Future Recommendations	146-147
	References	148-160



No.	Title	Page
Chapter	Introduction and Literature Review	1-37
One		1.57
(1-1)	Classification scheme for the various composite types	2
(1-2)	The structure of polymers	5
(1-3)	Schematic representation structure of epoxy resin, n denotes the number of polymerized subunits	6
(1-4)	Approximate tures of resoles	7
(1-5)	Approximate tures of novolacs	7
(1-6)	Classification of reinforcing material	10
(1-7)	The path of the crack for particulate composites under tensile strength	12
(1-8)	The relation between the yield strength over the reciprocal of the square root of distance between particles (D)	13
(1-9)	The change in the elasticity coefficient for particulate composites with volume fraction change.	14
(1-10)	The increment in rubber tensile strength when reinforced with particles from different types of carbon black	14
(1-11)	Classification of fiber reinforced composites	16
(1-12)	Idealized view of the dispersion of filler particles	20
(1-13)	Illustration of three polymorphs of ZrO2: (a) cubic, (b) tetragonal and (c) monoclinic	21
(1-14)	Molecular structure of a magnesium oxide (MgO) nanoparticle	22
(1-15)	Sandwich panels	23
(1-16)	Building blocks in fiber reinforced composites	24
(1-17)	Unidirectional laminates	25
(1-18)	Unidirectional and multidirectional laminates	25
(1-19)	Wettability of solid surface: Θ contact angle, γ L liquid surface tension, γ S solid surface tension, γ SL solid and liquid boundary tension, for a liquid drop on a solid surface	28
Chapter Two	Theoretical Part	38-62
(2-1)	(a) Brittle fracture none any plastic deformation, (b) Moderately ductile fracture after several necking, (c) Highly ductile fracture in which the sample necks down to a point	39
(2-2)	Brittle fracture surface, (A) very smooth mirror region near the origin of the fracture, with tear lines involving the remainder of the surface [14], (B) surfaces have lines or ridges that radiate from the origin of the crack into a fanlike pattern	40
(2-3)	Stages of cracking into amorphous polymers, region A: crack advance by void creation, region B: crack advance along alternate craze–matrix interfaces, region C: crack advance through craze bundle to form hackle bands	42
(2-4)	Illustrations of particle-filled polymers and changed cases of local processes, depending on distribution and particle size	43



No.	Title	Page
(2-5)	Crack pining for toughening of composite materials	44
(2-6)	Schematic of crack deflection mechanism	45
	Schematic stress-strain diagram, A-linear elastic deformation, B-	
	nonlinear elastic behavior, C, D-plastic deformations, E-Ultimate	
(2-7)	stress, F- Stress at failure, where region I is linear elastic deformation	46
	(brittle behavior) and region II is plastic deformation (ductile	
	behavior)	
(2-8)	(a) The three-point bend test, (b) The deflection and the thickness (d)	47
(obtained by bending	10
(2-9)	Three-point bending test setup and force distribution	48
(2-10)	Apparatus for impact testing of materials, specimen and loading	49
(0, 1, 1)	configuration for a) charpy pendulum and b) izod pendulum	7 1
(2-11)	1 wo different indenters of durometer hardness test	51
(2, 12)	Basic kinds of electric polarization: (a) electronic polarization, (b)	52
(2-12)	atomic of fonic polarization, (c) dipolar polarization and (d) interface	33
	The frequency dependence of polarizability showing some	
(2-13)	contribution mechanisms	57
	Illustration of interaction zones for (a) a microparticles and (b) an	
(2-14)	assembly of nanoparticles	58
(2-15)	Schematic diagram of Lee's disc	59
(2-16)	Fickian diffusion curve for polymer matrix composite	62
Chapter	Materials and Droperation Method	62.92
Three	Materials and Preparation Method	03-85
(3-1)	The step of experimental work of the research	64
(3-2)	(a) Epoxy resin component (A) sikadur (52LP), (b) Hardener	65
(32)	component (B) from sikadur	05
(3-3)	Phenol formaldehyde resin	65
(3-4)	(a) Kevlar-49 fibers, (b) Carbon fibers and (c) E-glass fibers	66
(3-5)	(a) Zirconium oxide nanoparticles and (b) Magnesium oxide	67
	nanoparticles	<u> </u>
(3-6)	Schematic illustration of hand-lay up	68
(3-7)	The casting mold consists of glass plates with dimensions (200 x 200 $\times 4$ mm)	68
. ,	X 4 mm)	
(3-8)	(a) Rotary head of (CNC) machine, (b) Specimens cutting by (CNC)	70
(3-0)	Tensile test equipment by tinius olsen UK model (HKT)	78
(3-10)	Bending test equipment by tinius olsen UK model (HKT)	79
(3-10)	Pendulum impact tester equipment time testing machines	79
(3-12)	Elcometer shore (D) hardness equipment	80
(3-13)	(a) Schematic of lee's disc and (b) Lee's disc equipment	81
(3-14)	LCR meter equipment	82
(3-15)	The water absorption test	82



Chapter Four	Results and Discussion	84-145
(4-1)	Stress-strain curves of tensile test for ER and ER/PF composite with (0-20%) of PF	85
(4-2)	Stress-strain curves of bending test for ER and ER/PF composite with (0-15%) of PF	87
(4-3)	Impact strength of ER/PF composite with various mass fraction of PF	89
(4-4)	Shore D hardness of ER/PF composite with various mass fraction of PF	91
(4-5)	Thermal conductivity of ER/PF composite with various mass fraction of PF	92
(4-6)	Dielectric constant of ER/PF composite with various mass fraction of PF as a function of frequency	93
(4-7)	Dielectric loss of ER/PF composite with various mass fraction of PF as a function of frequency	94
(4-8)	A.C. electrical conductivity of ER/PF composite with various mass fraction of PF as a function of frequency	95
(4-9)	The water absorption of ER/PF composite with various mass fraction of PF as a function of time	96
(4-10)	Stress-strain curves of tensile test for MgO and ZrO nanoparticles with 95%ER/5%PF	97
(4-11)	Stress-strain curves of bending test for MgO and ZrO nanoparticles with 95%ER/5%PF	98
(4-12)	Impact strength of MgO and ZrO nanoparticles with 95%ER/5%PF	99
(4-13)	Shore D hardness of MgO and ZrO nanoparticles with 95%ER/5%PF	101
(4-14)	Thermal conductivity of MgO and ZrO nanoparticles with 95%ER/5%PF	102
(4-15)	Dielectric constant of MgO and ZrO nanoparticles with 95%ER/5%PF	103
(4-16)	Dielectric loss of MgO and ZrO nanoparticles with 95%ER/5%PF	104
(4-17)	A.C. electrical conductivity of MgO and ZrO nanoparticles with 95%ER/5%PF	104
(4-18)	The water absorption of MgO and ZrO nanoparticles with 95% ER/5% PF	105
(4-19)	Stress-strain curves of tensile test for GF, CF and KF fibers with 95% ER/5% PF	106
(4-20)	Stress-strain curves of bending test for GF, CF and KF fibers with 95% ER/5% PF	107
(4-21)	Impact strength of GF, CF and KF fibers with 95%ER/5%PF	109
(4-22)	Shore D hardness of GF, CF and KF fibers with 95% ER/5% PF	110
(4-23)	Thermal conductivity of GF, CF and KF fibers with 95%ER/5%PF	111
(4-24)	Dielectric constant of GF, CF and KF fibers with 95% ER/5% PF	112
(4-25)	Dielectric loss of GF, CF and KF fibers with 95% ER/5% PF	112
(4-26)	A.C. electrical conductivity of GF, CF and KF fibers with 95%ER/5%PF	113
(4-27)	The water absorption of GF, CF and KF fibers with 95% ER/5% PF	114



No.	Title	Page
(4-28)	Stress-strain curves of tensile test for nano-MgO and GF, CF and KF	115
(4-29)	Stress-strain curves of tensile test for nano-ZrO and GF, CF and KF fibers with 95%ER/5%PF	115
(4-30)	Stress-strain curves of bending test for nano-MgO and GF, CF and KF fibers with 95% ER/5% PF	118
(4-31)	Stress-strain curves of bending test for nano-ZrO and GF, CF and KF fibers with 95%ER/5%PF	118
(4-32)	Impact strength of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	120
(4-33)	Impact strength of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF	120
(4-34)	Shore D hardness of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	122
(4-35)	Shore D hardness of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.	122
(4-36)	Thermal conductivity of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	125
(4-37)	Thermal conductivity of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF	125
(4-38)	Dielectric constant of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF/PF	126
(4-39)	Dielectric constant of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF/PF	127
(4-40)	Dielectric loss of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	128
(4-41)	Dielectric loss of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF	128
(4-42)	A.C. electrical conductivity of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	129
(4-43)	A.C. electrical conductivity of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF	129
(4-44)	The water absorption of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF	130
(4-45)	The water absorption of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF	130
(4-46)	Various pipes	133
(4-47)	Steps for designing pipes in a program solid work	136
(4-48)	Steps for analysis the results of pipes in a program ANSYS	138
(4-49)	Oil pan and Engine components	139
(4-50)	Steps for designing oil pan in a program solid work	142
(4-51)	Steps for analyzing the results of oil pan in a program ANSYS	144
(4-52)	Steps for analyzing the results of oil pan in a program ANSYS	145



No.	Title	Page
Chapter Three	Materials and Preparation Method	63-83
(3-1)	Resin materials and some of their properties	65
(3-2)	Fiber materials and some of their properties	66
(3-3)	Properties of the nanoparticles	67
(3-4)	Mixing ratio of epoxy resin and phenol resin	69
(3-5)	Mixing ratio of composite materials	70
(3-6)	Tensile test Samples of different types of composite materials	71
(3-7)	Bending test samples of different types of composite materials	72
(3-8)	Impact test Samples of different types of composite materials	73
(3-9)	Thermal conductivity test samples of different types of composite materials	75
(3-10)	Dielectric test samples of different types of composite materials	76
(3-11)	Water absorption test samples of different types of composite materials	77
Chapter Four	Results and Discussion	84-145
(4-1)	Tensile test of ER/PF blend with different mass fractions of addition	86
(4-2)	Bending test of ER/PF blend with different mass fractions of addition	88
(4-3)	Thermal conductivity of ER/PF composite with various mass fraction of PF	93
(4-4)	The parameters of tensile test for composite materials	116
(4-5)	The parameters of bending test for composite materials	119
(4-6)	Impact strength of composite materials	121
(4-7)	Hardness of composite materials	123
(4-8)	Dimeter and wall thickness of various pipes	132
(4-9)	Properties of plastic pipes material with ER/PF/nanoparticles and ER/PF/fibers	134
(4-10)	Properties of plastic pipes material with ER/PF/fibers/ nanoparticles	135
(4-11)	Properties of oil pan material with ER/PF/nanoparticles and ER/PF/fibers	140
(4-12)	Properties of oil pan material with ER/PF/fibers/ nanoparticles	141

2	List of Symbols	K

Symbol	Definition	unit
Wi	Mass fraction	
V_{f}	Volume fraction	
m _{fp}	Mean free path	cm
τ	Shear stress	Pa
$g_{\rm m}$	Shear coefficient	Pa
dp	The distance between particles	m
r _{pc}	Yield strength for particulate composite	N/m ²
σ	Stress	N/m ²
E	Strain	
e	Young's modulus	Pa
а	Area of a plane	m ²
f	The force	N
Δl	The elongation	
1	The instantaneous length	cm
lo	Original length	cm
ef	Young's modulus of flexural	Pa
$\sigma_{ m f}$	Flexural stress	N/m ²
$\epsilon_{\rm f}$	Flexural strain	
d	The deflection and the thickness	cm
m	Bending moment	N·m
m _m	Moment of resistance	N. m
е	The impact energy	$W \cdot m^{-2}$
g	The gravitational acceleration	m/s ²
u	Energy of fracture	J/m ²
i.s	Impact strength	J/m ²
3	Dielectric constant	
3	Static electric field	NC ⁻¹
р	Electric polarization	C/m ²
χ'	Electrical susceptibility	
ε'	Permittivity of material	F/m
٤٥	Permittivity of vacuum	F/m
ε''	Imaginary dielectric constant	
٤ _r	Relative permittivity of material	
٤*	Complex dielectric constant	F/m
ε _r ′	Dielectric loss factor	
tan δ	Tangent of loss angle	
r	Resistance of specimen	Ω
с	Capacitance	F
$\sigma_{\mathrm{a.c}}$	a.c. conductivity	$(\Omega.m)^{-1}$
W	Angular frequency	$\mathbf{rad} \cdot \mathbf{s}^{-1}$
q	Heat flux	$W \cdot m^{-2}$
k	Thermal conductivity	W/(cm·K)
А	Cross sectional area	m ²
T_1, T_2	The difference in temperature	K
X	The thickness of the sample	mm
h	Heat transfer coefficient	$W/(m^2K)$
r	Radius of the specimen disc	cm

	<u>a e</u>	
2	Abbreviations	K
		•

Symbol	Definition	unit
ER	Epoxy resin	
PF	Phenol formaldehyde resin	
ZrO	Zirconium oxide nanoparticles	
MgO	Magnesium oxide nanoparticles	
GF	Glass fibers	
CF	Carbon fibers	
KF	Kevlar fibers	
ASTM	American society for testing and materials	
CNC	Computer numerical control	
LCR	The inductance (L), capacitance (C) and resistance (R)	
meter		
MMCs	Metal Matrix Composites	
PMCs	Polymers Matrix Composites	
CMCs	Ceramic Matrix Composites	
CCCs	Carbon Carbon Composites	
FRP	Fiber reinforced plastics	
AFM	Atomic force microscopy	
MWCNTs	multi-walled carbon nanotubes	
CFRPs	carbon fibers reinforced polymers	
HMF	hot melting fibers	
PVC	polymerizing vinyl chloride	
ANSYS	Analysis System	
FeH	Upper yield point is the point after which the plastic deformation starts.	kN
FeL	Lower yield point is the point after which strain hardening begins.	kN
Fp	Proof force is an amount of force that a sample must be able to withstand	kN
	without permanently deforming.	
Rp	Proof stress is the point at which a particular degree of permanent	MPa
Doll Dol	Lipper and Lower stress point	MDo
Ken, Kel	Opper and Lower suess point.	wird



1.1 Introduction

Composite materials are quite common today and are used in nearly every segment of civilian and military industry. The idea of reinforcement is not new. Over the centuries natural fibers, such as grass or animal hair, have been used to improve the strength and to lessen the shrinking of pottery prior to firing and increase the strength in mud houses. This idea in the present form has been exploited with the development of glass, carbon and later of aramid fibers [1].

World war II led to the birth of glass-fibers-polyester composites for radomes and secondary aircraft structures, such as doors and fairings, which were designed and placed into production. Glass-fibers composites were recognized as valid space materials when they were picked for fabrication and production of polaris submarine missile casings. In the late (1950), research efforts focused on light weight elements in the search for fibers of even greater strength that could compete successfully in the marketplace with aluminum and titanium. Boron fibers were the first result of this effort (1963), followed by carbon, beryllium oxide, and graphite. A composite consisting of (80%) advanced polymer and (20%) aluminum has been developed for automotive applications [1].

The major advantages of composite materials are low density, high specific strength and stiffness, good corrosion resistance and improved fatigue properties. Because of these properties, they have successfully replaced many conventional metals [2,3]. Polymeric composite materials, for example, can solve some of the problems resulting from the deficiencies of conventional steel reinforced- concrete materials, and other polymeric materials in load-bearing structures in aircraft, automobiles, ships, pipelines, storage tanks, etc.

1.2 Composites

Composite materials are defined as materials creating from the combination of two or more substances, each with significant different physical or chemical properties than before creating, to form a new material properties different from the properties of each of the common materials in the structure and with a coherent structure resulting from the homogeneity of two different materials in terms of structure and usual composites consists of three phases matrix (continuous), dispersion (particulates, fibers) or reinforcing material structure and interface in composites [4]. Most developed composite materials thus far have been fabricated to improve mechanical properties such as strength, stiffness, toughness, and high temperature performance. It is natural to study together the composites that have a common strengthening mechanism. The strengthening mechanism strongly depends on the geometry of the reinforcement. Therefore, it is quite convenient to classify composite materials on the various composite types as shown in figure (1-1) [5].



Figure (1-1): Classification scheme for the various composite types [5].

1.2.1 Matrix Composites

Matrix phase is the most quantitative material that encloses the other components and give it the cohesion and connect of phases together to form a composite system [6]. The most common matrix composites can be divided into four main groups.

1.2.1.1 Metal Matrix Composites (MMCs)

Metal matrix composites (MMCs), like most composite materials, provide significantly enhanced properties over conventional monolithic materials, such as stiffness, and weight savings, while strength, continuous higher fiber reinforcement provides the most effective strengthening, particle reinforced materials are more attractive due to their cost-effectiveness, isotropic properties, and their ability to be processed using similar technology used for monolithic materials. Metals are reinforced to increase or decrease their properties to suit the needs of design, like elastic stiffness and strength of metals. Large coefficients of thermal expansion, thermal and electrical conductivities of metals can be reduced by the addition of fibers such as silicon carbide. (MMCs) have several advantages over (PMCs), like, higher elastic properties, high service temperature, in sensitivity to moisture, better wear and fatigue resistance [7].

1.2.1.2 Ceramic Matrix Composites (CMCs)

Ceramic matrix like alumina, calcium alumino silicate reinforced by fibers for example carbon or silicon carbide. Advantages of (CMCs) contain high strength, hardness, high service temperature edges for ceramics (1500°C), chemical inertness and low density and increases their fracture toughness because it causes slow failure of composite (CMCs) are finding increased uses in high temperature areas

where (MMCs) and (PMCs) cannot be used. Typical applications include cutting tool inserts in oxidizing and high temperature environments [8].

1.2.1.3 Carbon Carbon Composites (CCCs)

Carbon carbon materials are organic class of composites like the graphite, epoxy family of (PMCs). They contain a fibrous carbon substrate in a carbonaceous matrix, both constituents are of the same element. These materials can be made in wide variety of forms, from one- dimensional to n-dimensional. Carbon materials have higher stiffness and higher thermal conductivity coefficient (11.5 W/m.K) and chemical stability [9].

1.2.1.4 Polymer Matrix Composites (PMCs)

Polymers are commonly used because they have good mechanical properties and the manufacturability of fiber reinforced polymeric composites strongly depends on the properties of the matrix including viscosity, melting temperature and curing time. The main materials used are resins and based on the structure of polymer chains, there are many probable classifications of polymers according to [10]:

1- The Structure of Polymers:

a- Linear Polymers: Van der Waals bonding between chains as illustrated in figure (1-2a). Examples: poly (vinyl chloride), polyethylene, polystyrene and nylon.

b- Branched Polymers: Chain packing efficiency is decrease compared to linear polymers - lesser density as illustrated in figure (1-2b). For example, low density polyethylene (LDPE) contains short chain branches.

c- Cross-Linked Polymers: Chains are linked by covalent bonds as illustrated in figure (1-2c).

d- Network Polymers: Multifunctional monomers creating three or more active covalent bonds create three dimensional networks as illustrated in figure (1-2d).



Figure (1-2): The structure of polymers [7].

2- The Behavior of Polymers with Temperature Increase [11,12]:

a- Thermoplastic Polymers: Are long-chain molecules containing one or more repeating units have no primary chemical bond between them. These long chains of similar molecules are linked together by secondary forces called Van der waals forces and thermoplastics polymers soften when heated and temperature equal the glass transition (T_g) and their viscosity decreases as additional heat is applied. The heating process is completely reversible as no chemical bonding between molecules takes place. This characteristic allows thermoplastics to be remolded and recycled without negatively affecting their mechanical properties, examples of these polymers are polyethylene, polystyrene, polypropylene and nylon.

b- Thermosetting Polymers: Are crosslinking molecules and these crosslinking limit the movement of molecule chains and prevent the crystallization of molecules and increase the energy required to move the parts of polymer chains. For this reason, these polymers are often non-crystalline and have high degrees of glass transition (T_g). Therefore, thermoset polymers are ideal for high temperature

applications. In heating polymer, the chains are crosslinked and the polymers become insoluble, non-fusion and poorly conductive to thermal and electrical. Most of these resins are added hardener at room temperature or by heat source for example epoxy resins, unsaturated polyester resins. There are many types of these polymers like:

1- Epoxy Resin (ER)

One of the most commonly used thermoset polymers has been used as a base material in this dissertation research because of its low shrinkage during cure and excellent adhesion with various commercial fibers and fillers [10]. The structure of epoxy resin repeating unit is shown in figure (1-3).



Figure (1-3): Schematic representation structure of epoxy resin, n denotes the number of polymerized subunits [10].

2- Phenol-Formaldehyde (PF)

The (1940's) to (1960's) brought about much development in the chemistry of phenolic resole and novolac resins [13]. However, it was not until the (1970's) to (1980's) that much effort was made in the reinforced composites industry to use these resins [14]. The phenolic resins are made from phenols and formaldehyde, and they are divided into resole and novolac resins. The resoles are prepared under alkaline conditions with formaldehyde/phenol (F/P) ratios greater than one. On the

contrary, novolacs are prepared under acidic conditions with (F/P) ratios less than one. Resoles are cured by applying heat and/or by adding acids. The approximate tures of resoles are shown in figure (1-4) below. Novolacs are cured when reacting chemically with methylene groups in the hardener, the approximate tures of novolacs are shown in figure (1-5) below, the common procedure for curing phenolic novolac resins uses hexamethylenetetramine (HMTA) and releases volatiles during the cure, which produce networks with numerous voids. This results in materials that lack the toughness necessary for structural applications [15].



Figure (1-4): Approximate tures of resoles [14].



Figure (1-5): Approximate tures of novolacs [15].

Phenolics are particularly suitable for electrical applications because of their good dielectric properties, dimensional stability and resistance to moisture [13].

The phenolics are also rated for good resistance to high temperature, good thermal stability and low smoke generation. Finally, polymeric phenolic compounds have a wide range of applications, including fields such as aerospace, construction and electronics. There are three core reasons for the broad application range of these materials. First, the synthesis of phenolic prepolymers by electrophilic aromatic substitution is relatively simple and inexpensive. Second, methods for their conversion into thermoset networks are well established. Third, these networks are highly aromatic and thus, they are resistant to thermal oxidation [14]. Phenolic resins are well known for their excellent fire, smoke, and fast smoke toxicity properties (FST); retention of properties after long-term exposure to high temperatures; excellent electrical resistance; and excellent chemical resistance, especially in chlorinated solvents. However, they are also known to be quite difficult to pultrude due to their high viscosities, slow cure rates leading to slow pull speeds and high porosity content. Therefore, the efforts lead to development of a new series of low viscosity phenolic novolac resin systems process able at high speeds with excellent mechanical properties and outstanding fast strength tensile characteristics [14,15].

3- Polymer Blends

Polymer blends are widely used for both structural and non-structural applications including aerospace, automotive, electrical and electronic, building, and domestic industries. Advantages are their low processing cost, low density, insulation properties, and chemical resistance to aggressive media, large polymeric articles that cannot be molded require joining. There are a variety of methods available for joining of polymers, e. g. mechanical fasteners, adhesives, and welding [16].

In order to understand polymer blends, one must understand polymer as concept. Any substance that flows or gets deformed under influence of heat, pressure or both and retains the new form given to it when the stress is removed is called plastic material. Polymers of large molecules are found abundantly in nature such as wood, cotton, silk, wool, leather, rubber, shellac and some silicates. Their variety has been enormously increased by the chemists using synthetic means. Polymer blends are formulated to represent a very effective technique for modification of polymer properties. This is why there has been an increased awareness of polymer blends, particularly in the last decade. Polymers can be blended with other polymers [17].

The physical properties of the resulting blends would depend directly on several factors, namely the properties and the percentages of the original components, degree of compatibility and dispersion, the nature of the interaction that are utilized to produce those polymers [18]. The scientific and commercial progress in the polymer blends during the past two decades has been tremendous and is driven by realization that new molecules are not always required to meet needs for new materials and that blending can usually by implemented more rapidly and economically than the development of new chemistry. However, successful blend technology requires a sound scientific basis [19].

c- Rubbers and Elastomers Polymers: Rubber material is one which can be stretched to at least twice its original length and rapidly contract to its original length. Rubber must be a high polymer (polymers with very long chains) as rubber elasticity, "natural rubber" is a thermoplastic and in its natural form it becomes "soft" and "sticky" on hot days (not a good property for an automobile tire). In fact, until discovered a curing reaction with sulfur in (1839), rubbers were not crosslinked and did not have unique mechanical, rubber-elastic properties.

9

1.2.2 Based on Reinforcing Material Structure

The second phase is surrounded in the matrix in a discontinuous form, this secondary phase is called dispersed phase. Dispersed phase is typically stronger than the matrix, so it is sometimes called reinforcing phase [20]. There are many kinds of reinforcements such as fibers, particles, flakes and whiskers. Fibers provide the stiffest and strongest materials and for this reason they are also the most common method of reinforcing fiber reinforced plastics (FRP). The introduction of fibers into the matrix induces directionality or anisotropy in the material. Fibers reinforcement may be used in several different forms or arrangements, depending on their application and manufacturing route [21].

They are categorized in terms of length as short, long or continuous fiber which offer the highest mechanical properties, and give the possibility of using specific orientations to give the composite its directional properties. Based on the types of reinforcement used, the composites are classified as shown in figure (1-6).



Figure (1-6): Classification of reinforcing material [21].

They are available as lengths of fabric in different direction, all of which have different properties, processing characteristics and costs. These include unidirectional, biaxial, multiaxial, quadric axial and random orientation [22].

1.2.2.1 Particulate Composites

Particle fillers may be spherical, cubic, tetragonal, platelet or other regular or irregular shape to reinforced material. The particle can be either randomly oriented or preferred oriented. Particle fillers are broadly used to advance the properties of matrix materials such as to modify the thermal and electrical conductivities, increase performance at raised temperatures, reduce friction, increase wear and abrasion resistance, increase surface hardness and reduce shrinkage. Also, in case of particulate reinforced composites. Particulate composites consist of a matrix reinforced with a dispersed phase in form of particles. The effect of the dispersed particles on the composite properties depends on the particles dimensions. Largeparticle and dispersion-strengthened composites are the two sub classifications of particle-reinforced composites. The distinction between these is based upon reinforcement or strengthening mechanism. The term "large" is used to indicate that particle-matrix interactions cannot be treated on the atomic or molecular level. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of the matrix phase in the vicinity of each particle; the matrix transfers some of the applied stress to the particles, which bear a fracture of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrixparticle interface. For dispersion-strengthened composites, particles are normally much smaller, having diameters between (10 and 100 nm). Particle-matrix interactions that lead to strengthening occur on the atomic or molecular level [23].

Reinforcement by particles causes increment in the resistances of the composite material against distortion and this depends on the way of the particles dispersion in the matrix material. In this type of reinforcement, the size of the particle is less than $(0.1 \ \mu\text{m})$ and the mean free path ranges between $(0.01 \ -$

11

0.3 μ m). For analysis of this kind of reinforcement suppose the particles size, (Φ) and the volume fraction (V_f) and the mean free path, (m_{fp}) one can calculate it from the following relation [24].

$$m_{fp} = 2 \Phi / 3 V_f$$
(1-1)

and to calculate the shear stress (τ) the following relation is used.

Where G_m : the shear coefficient, D_p : the distance between particles and b: Burger's factor.

The relation (1-2) shows that composite resistance is inversely proportional to dispersed particles thus when distance between the particles decreases the movement of dislocations in the matrix decreases as shown in figure (1-7) [24,25].



Figure (1-7): The path of the crack for particulate composites under tensile strength [25].

The particle size in this type of reinforcement is higher than $(1\mu m)$ and the mean free path for the matrix material is higher than $(1\mu m)$. The principle of its use is similar to that of dispersion strengthening because it prevents distortion of the matrix materials. In addition, it bears the applied stresses on the composite due to its large volume as shown in figure (1-8), the yield strength for particulate composite (R_{pc}) is inversely proportional to the square root of the distance between particles, (D) according to the relation [24].



Figure (1-8): The relation between the yield strength over the reciprocal of the square root of distance between particles (D) [24].

Normally fillers are used to change the thermal, electrical and mechanical properties of the matrix. The coefficients of particulate composites near the minimum values of composites reinforced with fibers as shown in figure (1-9) when sand is mixed with polymer this will be much cheaper than in case of well-arranged glass fibers in the same polymer. For this reason, the slight increment in the hardness as a result of particles addition is economically important. Naturally the resulting particulate composite becomes isotropic instead of anisotropic as in case of fibers composites and this may be very beneficial in case of some applications which require isotropic characteristics. The filtered polymers may be formed and molded in normal ways, and for this reason they are manufacturing cheaply, they appear in the modern automobiles as dumpers, front windows
bumpers, and shield external pieces. The following diagram in figure (1-10) shows the increment in rubber tensile, strength when reinforced with particles from different types of carbon black [23,24].



Figure (1-9): The change in the elasticity coefficient for particulate composites with volume fraction change [24].



Figure (1-10): The increment in rubber tensile strength when reinforced with particles from different types of carbon black [23].

1.2.2.2 Fibers Reinforced Composites

Reinforced composite materials by fiber materials which consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces (boundaries) between them. In this form, both fibers and matrix keep

their physical and chemical identities but they make a combination of properties that cannot be done with either of the constituents acting individually. In general, fibers are the major load-carrying members, while the framing matrix holds them in the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages due to elevated temperatures and humidity. The main fibers in commercial utilize are different types such as glass, carbon and kevlar (49). Other fibers, like boron, silicon carbide and aluminum oxide, are used in restricted quantities. All kinds of fibers combined with a matrix may be in fibers continuous lengths or in fibers discontinuous (short) lengths. The laminate is most common form in which fiber-reinforced composites are used in structural applications, it is made by stacking a number of thin layers of any kind of fibers and matrix and combining them into the required thickness. Fibers-reinforced composite materials are generally classified such as single layer and multi-layer composites on the basis of studying both the theoretical and experimental properties. Single layer composites may essentially be made from some distinct layers with each layer having the similar orientation also properties and so the total laminate can be measured as a single layer composite. Multilayered composite materials are most composite materials used in structural applications; they contain of numerous layers of fibrous composites. Each layer or lamina is a single layer composite and its orientation is various according to design. Some of identical or different layers are bonded together to form a multilayered composite practical for manufacturing applications. When the essential materials in each layer are the similar, they are called simply laminates. Hybrid laminates denote multilayered composites which containing of layers prepared from different essential materials [26,27]. Fiber reinforced composite materials in a single layer composite could be short or long related to its overall dimensions. Composite materials using long fibers are called continuous fiber reinforced composite

materials and composite materials that using short called discontinuous fibers reinforced composite materials as it shown in figure (1-11). Continuous fibers reinforced composite materials in single layer composites may be all aligned in one direction to form a unidirectional composite material. Such composite materials are made-up by laying the fibers parallel and saturating them with any resinous materials. A single layer in mutually perpendicular directions to form the bidirectional reinforcement materials such as in a woven fabric. The bidirectional reinforcement materials in two perpendicular directions are almost equal. Discontinuous fibers cannot be simply controlled the composite materials orientation. Therefore, discontinuous fibers may be either randomly oriented or preferred oriented.



Figure (1-11): Classification of fiber reinforced composites [26].

In most cases, the fibers are artificial to be randomly oriented in the composites. However, in the injection molding of a fiber reinforced polymer, considerable orientation can occur in the flow direction and which a case of preferred oriented fibers in the composites so the types of fibers are [27]:

1- Glass Fibers

Glass fibers are glass compounds from silica that have some metal oxides which can be tailored to make different kinds of glass fibers. Silica is the main oxide in the form of silica sand and the other oxides such as Ca, Na and Al are combined to decrease melting temperature and impede crystallization. The most common type of glass fiber is E-Glass fibers that have low alkali consist of approximately (2%). E-glass is used in all common purpose structural applications and construction industry because its improved physical properties such as thermal conductivity and electrical resistance.

Glass fibers are mostly a good impact resistant but have weighs higher than carbon fibers or aramid such as kevlar fibers. Glass fibers has good features, equal to or better than steel in certain forms. The lower modulus needs to distinct design management where stiffness is critical. Composites prepared from these materials display great physical properties such as electrical, thermal and insulation properties. Glass fibers are used in radar antenna applications because their transparent to radio frequency radiation [27].

2- Carbon Fibers

Carbon fibers are prepared from organic precursors it is containing polyacrylonitrile (PAN), pitches with rayon and these the latter two usually applied for fibers at low modulus. The "carbon" and "graphite" fibers are usually utilized interchangeably, while graphite technically denotes to fibers that are bigger than (99 %) carbon composition and (93%-95%) for (PAN-based) carbon fibers. Carbon fibers have the maximum strength and stiffness of all the fibers-reinforced composite. Action carbon fibers in high temperature is mainly excellent. Carbon fibers reinforced polymer of composites are more brittle than glass or aramid fibers

composites. Glass and resin barriers are used with carbon fibers to prevent galvanic corrosion when used next to metal materials [28].

3- Aramid Fibers

Aramid fibers or polyaramids are the best major synthetic fibers are aramid. Aramid fibers are an aromatic polyimid that organic fabricated fibers for reinforced composite materials. Aramid fibers have perfect mechanical properties at a low density with the extra benefit of toughness and impact resistance. Aramid fibers have higher tensile strength, a medium modulus and lower density than glass and carbon fibers. Aramid fibers are weak electricity and thermal conductivity and rise the impact resistance of composite materials and unaffected by organic solvents, fuels and lubricants. Aramid composite materials are better compressive strength than glass or carbon composite materials. Dry aramid fibers are tough and utilized as cables or ropes, and often utilized in ballistic applications. Kevlar fibers are the best famous pattern of aramid fibers. Aramid is the major organic reinforced composite materials alteration for steel reinforced conveyor belt in car tires [28].

1.2.2.3 Hybrid Composite Materials

Hybrid composite materials are generally combined with more than two different kinds of fillers particularly fibers in a single matrix. Hybridization is generally applied for enhance the properties and for decreasing the fee of classical composite materials. Hybrid composites have different kinds of categorized according to the technique in which the composite materials are combined. Hybrid composite materials are designated as (i) sandwich type, (ii) interply, (iii) intraply and (iv) intimately mixed. In sandwich hybrids, one from any kinds of material is sandwiched between layers of another, whereas in interply, alternate layers of two or more materials are stacked in regular manner. Rows of two or more constituents are arranged in a regular or random manner in intraply hybrids while in intimately mixed type, these constituents are mixed as much as possible so that no concentration of either type is present in the composite materials [29].

1.2.2.4 Nanoparticles

Nanoparticles are defined as solid particles with a size in the range of (1-100 nm). There are some methods for synthesis nanoparticles like, Physical Vapor Deposition, the Sol-Gel manner, Chemical Vapor Deposition, Micelle and Inverse Micelle manner, Hydrothermal method and grinding with iron balls [30,31]. The conversion from microparticles to nanoparticles yields considerable changes in physical properties. Every property has a specific length scale, and if a nano-scale item is making smaller than the critical length scale, the fundamental physics of that property change drastically [32]. Nanoscale materials have a large surface area for a given volume, in the case of particles, the surface area per unit volume is inversely proportional with the particle diameter, thus, the smaller the diameter the greater the surface area per unit volume therefore, a change in particle diameter, from micrometer to nanometer range. Since many important physical and chemical interactions are ruled by surfaces and surface properties, a nanostructured material can have substantially different properties from a larger-dimensional material of the same composition, therefore the properties of nanoparticles are usually size dependent, and, when prepared in nanometer-size, materials exhibit unique properties [32,33]. Nanoparticles are generally described as primary or ultimate particles, aggregates and agglomerates as shown in figure (1-12). In some instance these particles types are easily distinguishable but in others there can be noticeable overlapping. The need is to distinguish between collections of particles that are weakly and strongly bonded together the term agglomerate for weakly bonded particle groups and aggregate for strongly bonded ones [34]. Many physical attributes are depending on size like [35,36]:

19



Figure (1-12): Idealized view of the dispersion of filler particles [34].

1- Improved sintering and hardness properties, where the process of heat treatment of porous structures, which occur through the pressing of powders, resulting in a reduced of the porosity of the compressed material, so the successful sintering improving the hardness of materials.

2- Decrease brittleness and improved ductility and super plasticity, where the brittle materials can be ductilized by decrees their grain size and super the brittle materials can be ductilized by decrees their grain size.

3- An increase in dielectric constant and electrical resistance can been observed.

4- An effect on optical properties like TiO_2 were found to become most efficient (UV) absorbers. There are many types of nanoparticles like:

1- Zirconia (ZrO₂) Nanoparticles

Zirconium dioxide (ZrO_2), which is also denoted to as zirconium oxide or zirconia, is an inorganic metal oxide that is largely used in ceramic materials [37]. There are many different ways of producing ZrO_2 nanosized powders, such as hydrothermal processing sol-gel processing and ion exchange manufacture methods [38]. Pure ZrO₂ exhibits three crystalline phases. Pure zirconia is monoclinic (M) at room temperature. This phase is stable up to (1170 °C). It will transform into a tetragonal (T) phase under higher temperatures and later into a cubic phase (C) at (2370 °C) as shown in figure (1-13) which illustrate ZrO₂ in three main crystalline structure phases: (a) cubic, (b) tetragonal and (c) monoclinic [39]. Zirconia is used in different fields of chemistry such as ceramics and catalysis [40]. Nano-zirconia ceramics are of great attention for their obvious enhancement in strength and toughness. Its high hardness, low reactivity and high melting point (2715 °C) which change mechanical property, thermal performance, electrical performance and optical performance of ceramic components [41].



Figure (1-13): Illustration of three polymorphs of ZrO₂: (a) cubic, (b) tetragonal and (c) monoclinic [42].

2- Magnesia (MgO) Nanoparticles

The magnesium oxide (MgO) is a very suitable material for insulation applications due to their low heat capacity and high melting point (2850 ^oC). MgO is obtained by thermal decomposition of different magnesium salts. The crystal structure of magnesium oxide is cubic, as shown in figure (1-14) [43]. MgO is used as a dielectric layer due to its excellent properties such as high dielectric constant (~9.8), large band gap in the range of (7.3 eV-7.8 eV) and higher breakdown field

(12 MV/cm) compared to commonly used dielectric layer [43]. Magnesium oxide nanoparticles can be applied in electronics and coatings fields [44].



Figure (1-14): Molecular structure of a magnesium oxide (MgO) [43].

1.2.2.5 Structure of Composite Materials

A laminate is fabricated by stacking numbers of lamina. It made up of two layers or a series of layers, each layer consisting of a reinforcing fiber imbedded in a matrix. Every layer is oriented in a predetermined manner in order to maximize the properties of the laminate [45]. Structural of composite materials divided into:

1. Sandwich Panels Composite Materials

The sandwich structural composites are divided into two types, cladded metal structure and honeycomb sandwich structure. In these structure thin, stiff, light weight structure, low cost, high bending, torsional and dense face sheets are bonded to a thick low-density core has received wide acceptance in weight-critical structures such as airplane parts, ship hulls and wind turbine blades [46], as shown in figure (1-15).



Figure (1-15): Sandwich panels [46].

2- Laminated Composite Materials

A laminate is a stack of lamina, as illustrated in figure (1-16), oriented in a specific manner to achieve a desired result. The mechanical response of a laminate is different from that of the individual lamina that forms it. The laminate's response depends on the properties of each lamina, as well as the order in which the lamina is stacked [46].

Based on the orientation of the fibers in the lamina, the laminated composites are classified into (5 types) as follows [47]:

1- Unidirectional Laminates

The fibers are parallel to the direction of the load application and are oriented in a single direction are shown in figure (1-17). The advantages of unidirectional layers are:

a- They have high rigidity (maximum number of fibers in one direction).

b- The ply can be used to wrap over long distance. Then the load transmission of the fibers is continuous over large distance.

c- They have less waste.

2- Bidirectional Laminates

The fibers are arranged in two directions in the matrix of each lamina. The fibers can be oriented in different directions in different lamina.

3- Woven Fabric Laminates

The fibers in these laminates are in the form of textile fabric which is produced by interlacing strands at more or less equal to right angles, the advantages of woven fabric laminate:

a- They provide properties that are more balanced in the (0 to 90) degrees directions than unidirectional laminates.

b- The fabrication time is less compared to that of multidirectional laminates



Figure (1-16): Building blocks in fiber reinforced composites [47].



Figure: (1-17) Unidirectional laminates [47].

.4- Interply Hybrid Laminates

It is possible to combine different kinds of fibers to form either an interply or an intraply hybrid laminate. An interply hybrid laminate consists of different kinds of fibers in different laminas, whereas an intraply hybrid laminate consists of two or more different kinds of fibers interspersed in the same lamina.

5- Multidirectional Laminates

The fibers can be oriented in any direction in the lamina. The fibers can be arranged in different directions in different laminas as shown in figure (1-18).

Design of a laminated composite involves constraints on optimizing. The constraining factors are listed as follows [48]:



Figure (1-18): Unidirectional and multidirectional laminates [46].

1- Cost, the cost of raw materials and the fabrication costs need to be kept in mind.

2- Mass, it's an important factor as related to aerospace and automobile industry to reduce energy cost.

3- Stiffness (to limit deformations) related to aircraft skins to limit buckling.

4- Thermal and moisture expansion coefficients as related to space antennas to maintain dimensional stability. Some of the mechanical design issues are discussed below:

a- Environmental Effects: Temperature and humidity plays a vital role in the life of the composite. These may lower the adhesion of the fiber's matrix interface, such as between glass and epoxy. Epoxy matrices softer at high temperature effecting properties.

b- Interlaminar Stresses: Are developed due to the mismatch of elastic module and angle between the layers of laminated composites. These are developed between the layers. These stresses can cause edge delamination of layers thus reducing the life of the laminated structure.

c- Impact Resistance: Impact reduces the strength of the laminates and also initiates delamination in composites. The impact resistance depends on interlaminar strength, stacking sequence and nature of the impact, such as velocity, mass and size of the impacting object.

d- Fracture Resistance: Mechanics of fracture is not simple due to: first, cracks developed in a composite can grow in the form of fibers breaks, matrix and deboning between layers. Second, no single critical stress intensity factors and strain energy release rates determine the fracture mechanics process.

e- Fatigue Resistance: The structures subjected to repeated cycles of loading reduce the life of the composite. The factors influencing fatigue properties are:

the laminate stacking fibers and matrix properties, fibers volume fraction and interfacial bonding.

1.2.3 Based on Interface in Composite Materials

A surface is formed by a common boundary of reinforcing fibers and matrix that is in contact with and maintains the bond in between for the transfer of loads. It has physical and mechanical properties that are unique from those of the fibers or the matrix characterization of the mechanical properties of interfacial zones is necessary for understanding mechanical behavior. In fact, the mechanical characteristics of a fibers/matrix composite depend primarily on the mechanical properties of the combined material, the surface of the fibers and the nature of the fibers/matrix bonding as well as the mode of stress transfer at the interface. Among the many factors that govern the characteristics of composites involving a fibrous material, such as carbon, glass, or ceramic and a macromolecular matrix, is the adhesion between fibers and matrix plays a predominant part. The stress transfer at the interface requires an efficient coupling between fibers and matrix. It is important to optimize the interfacial bonding since a direct linkage between fibers and matrix gives rise to a rigid, low impact resistance material [49].

1.2.3.1 Fibers-Matrix Interface Adhesion

The fibers-matrix adhesion is important in determining the mechanical, dynamic mechanical and rheological characteristics of the composites. The fibers-matrix interface adhesion can be explained by five main mechanisms [49,50]:

1- Adsorption and Wetting

This is due to the physical attraction between the surfaces, which is better understood by considering the wetting of solid surfaces by liquids. Between two

27

solids, the surface roughness prevents the wetting except at isolated points. When the fibers surface is contaminated, the effective surface energy decreases. This hinders a strong physical bond between fibers and matrix interface. Wettability can be defined as the ability of a fluid phase to preferentially wet a solid surface in the presence of a second immiscible phase. Good wetting of fibers by matrix material during the impregnation stages of fabrication is a prerequisite to proper consolidation of composites, particularly for composites based on polymer resins and molten metals. Liquids that form contact angles greater and less than (90°) are respectively called 'non-wetting' and 'wetting', as shown in figure (1-19).



Figure (1-19): Wettability of solid surface: Θ contact angle, γ_L liquid surface tension, γ_S solid surface tension, γ_{SL} solid and liquid boundary tension, for a liquid drop on a solid surface [49].

2- Inter Diffusion

Polymer molecules can diffuse into the molecular network of the fibers surface. The bond strength will depend on the amount of molecular conformation, constituents involved and the ease of molecular motion.

3- Electrostatic Attraction

This type of linkage is possible when there is a charge difference at the Interface. Introduction of coupling agents at the interface can enhance bonding through the attraction of cationic functional groups by anionic surface and vice versa.

4- Chemical Bonding

Chemical bonds can be formed between chemical groups on the fibers surface. Interfacial chemical bonding can increase the adhesive bond strength by preventing molecular slippage at a sharp interface during fracture and by increasing the fracture energy by increasing the interfacial attraction.

5- Mechanical Adhesion

Mechanical interlocking at the fibers-matrix interface is important. The degree of roughness of the fibers surface is very important in determining the mechanical and chemical bonding at the interface. This is due to the larger surface area available on a rough fiber. Surface roughness can increase the adhesive bond strength by promoting wetting or providing mechanical anchoring sites.

1.2.3.2 Factors Affecting the Properties of Polymer Matrix Composites [50]:

1- Interfacial Adhesion

The behavior of a composite material is explained on the basis of the combined behavior of the reinforcing element, polymer matrix and the fibers/matrix interface. To attain superior mechanical properties, the interfacial adhesion should be strong. Matrix molecules can be anchored to the fibers surface by chemical reaction or adsorption, which determine the extent of interfacial adhesion. The developments of the atomic force microscopy (AFM) and nano indentation devices have facilitated the investigation of the interface [51].

2- Shape and Orientation of Dispersed Phase

Particles have no preferred directions and are mainly used to improve properties or lower the cost of isotropic materials. The shape of the reinforcing particles can be spherical, cubic, platelet, or of regular or irregular geometry. Particulate reinforcements have dimensions that are approximately equal in all directions. Large particle and dispersion-strengthened composites are the two subclasses of particle-reinforced composites. A laminar composite is composed of two-dimensional sheets or panels, which have a preferred high strength direction as in wood. The layers are stacked and subsequently cemented together so that the orientation of the high strength direction varies with each successive layer.

3- Properties of the Matrix

Properties of different polymers will determine its applications. The chief advantages of polymers as matrix are low cost, easy process ability, good chemical resistance and low specific gravity. On the other hand, low strength, low modulus and low operating temperatures limit their use. Varieties of polymers for composites are thermoplastic polymers, thermosetting polymers, elastomers and their blends.

1.3 Nanocomposites

A fast-developing area in composites research involves the field of nanocomposites. Polymer nanocomposites are mixtures of polymers and nanometer length scale reinforcement, whereas, conventional polymer composites contain micrometer scale particles. The advantages of nanocomposites over microcomposites include reduced filler amount and better properties than that obtained for the conventional composites. Three types of nanocomposites can be distinguished depending on the dispersed particles in the nanometer range, as follows:

1- Nanocomposites that can be reinforced by isodimensional nanofillers which have three dimensions in the nanometer range like spherical silica nanoparticles obtained by sol-gel methods [52] or by polymerization promoted directly from their surface.

2- Nanocomposites which can be reinforced by fillers which have only two dimensions in the nanometer scale, like carbon nanotube or cellulose whiskers.

3- The reinforcing phase, in the shape of platelets, has only one dimension on a nano-level like clays and layered silicates [53].

1.3.1 Polymer Nanocomposites

Polymer nanocomposites are defined as an interacting mixture of two phases, a polymer matrix and a solid phase which is in the nanometer size range in at least one dimension. Very significant feature for polymer nanocomposites is that the small size of the fillers leads to a dramatic increase in interfacial area creates significant volume fraction of interfacial polymer interaction with nano-fillers forming properties unlike from the bulk polymer until at low concentration of nano-fillers [48]. In particle - polymer structure creation, two effects play a significant role in the reinforcement; particle - polymer and particle-particle interactions, when particle – polymer interactions are generally the determining operator for the strength of the structure of polymers. Therefore, polymer nanocomposites complete significant enhancements in mechanical, thermal, electrical and optical properties at low filler concentrations, without increase in density [54,55].

1.3.1.1 The Factors that Effect on Polymer Nanocomposites Properties

There are many operators that effect on the polymer nanocomposite properties [33,56,57]:

1- Kinds of nanoparticles and their surface curing, distribution and dispersion of nanoparticles in the polymer matrix, size and shape.

2- The kinds of synthesis methods.

3- Polymer nanocomposite morphology.

4- Polymer matrix crystallinity, molecular weight, polymer chemistry and the kind of polymer, thermoplastic, thermosetting or elastomers.

1.3.2 Epoxy Nanocomposites

Epoxy nanocomposites are one of the most significant polymer nanocomposites because of the wide range of epoxy applications in industry, the epoxy resins have low density of epoxy about (1.05 - 1.3 g/cm³) and good adhesive. Epoxides are amorphous structure and highly cross-linked polymers, the structure of cross-linked polymer also preforms to an unwanted property such as; poor resistance to crack initiation and growth relatively brittle materials, one way to enhance these disadvantages can be completed by filling with nanoparticles when the special properties of nanoparticles leading to enhance the material properties [57]. Some advantages predictable from the reinforcement of nanoparticles are like improved some mechanical properties, (fracture toughness, modulus of elasticity and impact strength, scratch and abrasion resistance) improved dielectric properties, improvement of heat distortion, chemical resistance, weathering stability and durability [58].

1.3.3 Hybrid Organic/Inorganic Nanocomposites

Polymer-based organic/inorganic nanocomposites have gained increased attention in the field of material science. Homogeneously dispersed nanoscale inorganic filler particles in a polymer matrix improve the mechanical properties of the resulting nanocomposite. The objective of realizing polymer/particle nanocomposites with much smaller particles and largely improved particle dispersion have led to completely new materials in which favorable mechanical characteristics of organic polymers and inorganic materials are combined. Such nanocomposites show a significant improvement in stiffness, toughness, impact resistance and hardness when compared with the pure polymer [59].

1.4 Literature Review

This part summaries the topical reports issued in literature on mechanical and physical behavior of polymer matrix composites with special fibers reinforced composite materials and nanoparticles filled polymer composites.

1- Nagalingam et. al. (2010) in this study, the tensile strength, impact strength and fatigue life of an experimentally produced nanocomposite fiber reinforced plastics in various combinations of polyester resin, fiber and nanopowder was investigated at room temperature. The nanocomposite fiber reinforced plastic has sufficiently high ultimate tensile strength and 23% improvement of ultimate tensile strength at 5wt% increment of nanopowder. Impact strength increases to 10 J/mm², an addition of 10wt% of nanopowder. The influence of nanoparticle in FRP greatly increase tensile strength, impact strength [60].

2- Manjunatha et. al. (2010) reported that the fatigue life of 10 wt.% silica nanoparticle-modified bulk epoxy is about three to four times higher than that of neat epoxy. Silica nanoparticle debonding and subsequent plastic

33

void growth absorb energy and contribute towards the enhanced fatigue life for the nanoparticle modified epoxy. The fatigue life of the GFRP composite with 10 wt.% silica nanoparticle-modified epoxy matrix is four times higher than that of the GFRP with the neat epoxy matrix. [61].

3- Lingaraju et al. (2011) observed that wear rate increases with increasing applied load, time and sliding speeds through the effects of nanoparticles as fillers in glass–epoxy composite systems on the mechanical and tribological properties such as tensile strength, impact strength, flexural strength and hardness have been studied in accordance with (ASTM) standards. Addition of 2 wt% of HNT found 28% improvement of impact strength, 12% improvement in tensile strength, 4.2% improvement in hardness and 490% improvement in wear rate. Addition of 1 wt% of silica showed improvement of 6.6% in impact strength, 2.09% in tensile strength, 2% improvement of Barcoll hardness and 750% reduction in wear rate. [62].

4- Devendra and Rangaswamy (2012) studied epoxy composites materials reinforced by E-glass fibers filled by Al_2O_3 , Mg (OH)₂, SiC and experimental from the obtained results it is observed that composites filled by (10% Vol) Al2O3 and Mg (OH)2 exhibited low thermal conductivities. Composites filled by (10% Vol.) SiC exhibited maximum thermal conductivity (3.515 W/m °C). Hematite filled composites exhibited high thermal conductivities when compared with Al_2O_3 and Mg (OH)2 filled composites [63].

5- Rajmohan et. al. (2013) investigated the use of different nanoparticles mixed in different polymers. In the investigation nano-copper oxide (CuO) materials dispersed in polystyrene resin were used as matrix face for glass fibers reinforced plastics which is manufactured by hand layup processes. The results indicated that the predicted values through the developed model were in agreement with the

experimental results and with increase in weight fraction of nano CuO lead to improving in the mechanical properties [64].

6- Wereszczak et. al. (2013) studied the thermally conductive and electrical insulator of MgO filled epoxy molding compounds. A maximum bulk thermal conductivity of 3 W/mK was achieved with a 56% volume fraction of MgO filler. This 56vol% MgO-filled epoxy molding compounds has a thermal conductivity approximately twice that of traditional silica-filled epoxy molding compounds with the same volume fraction of filler and has equivalent electrical insulative [65].

7- Manjunath et. al. (2014) studied mechanical properties as tensile, flexural and moisture absorption properties of composites made from areca fibers, maize powder filler particles and epoxy resin and prepared by hand lay-up techniques. It is noted from the tensile test that the specimens prepared with reinforcement of areca fiber to epoxy maize powder filler of different weight fractions of 80:10:10 and 90:5:5 gives higher tensile strength than weight fractions of 80:20 and 90:10 of the specimens prepared without reinforcement of areca fibers to epoxy coconut shell filler. The more the fiber content, the higher tensile strength. [66].

8- Haribabu and Prasad (2015) studied composite material are E-glass fibers epoxy resin filler with nano-CaCO₃. The specimens are prepared by hand lay-up method. It is found that the reinforcing and toughening effects of the E-glass epoxy hybrid composites are increased by adding nano-CaCO₃. The tensile strength, strain, Young's modulus and energy at max load of these composites increased nonlinearly with the addition of the nano-CaCO₃ [67].

9- Mohanty and Srivastava (2015) investigated nano scale dispersion due to the size transformation of the reinforced particles from micron size to nano size in the polymer matrix to enhance the mechanical properties of fibers-reinforced hybrid composite. The materials are used: alumina nanoparticles and glass/carbon fibers reinforced hybrid composites resulted enhancements in the mechanical properties are mainly due to the better stress transfer properties from fibers and nanoparticles to the matrix [68].

10- Banakar et. al. (2016) studied tensile properties of epoxy resin composites reinforced with glass fibers. The effect of fibers orientation and thickness of laminates and the laminates were obtained by hand layup process. The laminated specimens with lesser thickness lead to more ultimate tensile strength irrespective fibers orientations. Specimen sustain greater load in [90:0] orientation specimens than in other orientations. Young's modulus of specimens increases with decrease in thickness. Extension is minimum in case of [90:0] orientations and maximum in case [30:0] orientations [69].

11- Bozkurt et. al. (2017) studied nanoparticles in composite materials is emerged as a result of increasing demand for the advancement in material properties to satisfy the market necessities. This study presents the effects of nano silica inclusion on tensile and flexural characteristics of glass/epoxy fibers reinforced composite laminates. Results obtained from specimens having nano silica particles showed the serious improvement on the tensile strength, flexural modulus and flexural strength values compared to specimens without nano silica inclusion [70].

12- Batabyal et al. (2018) studied fibers reinforced polymer composite materials are gradually substituting traditional metallic materials. A comparison of mechanical properties and erosion resistance has been investigated for glass and carbon fibers composites. It is observed that with increase in molding load, the tensile strength, modulus and wear resistance decreases [71].

13- Bulut et. al. (2018) studied compares the tensile and impact characteristics of kevlar, carbon and glass fibers reinforced composites with addition of microscale

silicon carbide (SiC) within the common matrix of epoxy. It is concluded from results that the content of SiC particles and fibers types used as reinforcement are major parameters those effecting on tensile and impact resistance of composites as a result of different interface strength properties between particles-matrix and particles-fibers [72].

14- Ahmadijokani et. al. (2019) investigated the effect of short carbon fibers on the tribological behavior of phenolic resin-based friction materials, a reference friction composite holding various ingredients without short carbon fibers and three friction composites holding (1, 2 and 4 vol%) carbon fibers were formulated. The results obtained from dynamic-mechanical analysis, thermogravimetric analysis was employed to investigate the worn surface of the samples and justify the aforementioned tribological behavior [73].

1.5 Aim of the Work

The aim objective of this work is to study the physical property represented by mechanical, electrical and thermal behavior of the hybrid composites (epoxy and phenol resins) reinforced by 1% nanoparticles (ZrO and MgO) and 1% fibers (glass, carbon, kevlar). Through the results of physical tests of the samples, the optimum values will be determined of modulus of elasticity of tensile and bending, impact strength, hardness, dielectric properties, thermal properties and the water absorption. This information and measurements have been inputted into a simulation program is finite element analysis (FEA) for plastic pipes and oil pan of an internal combustion engine to find out how efficient models manufacturing process in the laboratory.



2.1 Mechanical Properties

Materials are often subject to forces (loads) when they are used. Therefore, they deform (elongate, compress) or break as a function of applied load, time, temperature and other conditions. Learning more about these mechanical properties can be done by testing materials. Important mechanical properties are flexural strength, flexural modulus, fracture toughness, hardness and impact strength [74,75]. In general, the addition of inorganic fillers into a polymer produces an increment in stiffness, but losses toughness, whereas addition of nanoparticles increases toughness, but decreases stiffness. The addition of nanoparticles into polymer matrix at low fillers concentrations has caused in remarkable combination of high toughness and stiffness [76]. Results from the tests depend on the size and shape of material to be tested (specimen), how it is held, and the way of performing the test. That is why we use common procedures, or standards, which are published by the (ASTM).

2.1.1 Fracture

Fracture is the divided of a body into two or more pieces in response to an imposed stress that is static (i.e. constant or slowly change with time) and at temperatures that are low relative to the melting temperature of material. The imposed stress may be compressive, tensile, flexural, shear, or torsion [77,78]. There are two kinds of fracture: brittle and ductile classification built on the ability of material to experiment plastic deformation [79]. Fracture process includes two steps; crack creation and propagation in response to an applied stress. The creation of cracks may be capable to appear into a structure by three methods. First, they can present in a material because of its composition, as second-particles phase debonds in composites, and third, they can be generated during the service life of an element such as fatigue cracks. Crack creation also strongly relies on the microstructure of a specific crystalline or amorphous solid, imposed loading and environment. The microstructure plays a very significant role in a fracture process because of dislocation motion, grain size and kind of phases creation up the microstructure. All these microstructural features are imperfections and can act as fracture nuclei under unfavorable conditions [74,80].

2.1.1.1 Ductile Fracture

Ductile fracture is characterized by extensive plastic deformation in the vicinity of an advancing crack (Ductile fracture occurs well after the maximum load is reached and a neck has formed). Furthermore, the process proceeds relatively slowly as the crack (such a crack is often said to be stable) length is extended. That is, it resists any further extension unless there is an increase in the applied stress. Figure (2-1) shows schematic representations for two characteristic macroscopic ductile fracture profiles [78].



Figure (2-1): (a) Brittle fracture none any plastic deformation, (b) Moderately ductile fracture after several necking, (c) Highly ductile fracture in which the sample necks down to a point. [78].

The configuration shown in figure (2-1c) is founded for extremely soft metals, such as pure gold and lead at room temperature and other metals, polymers and

inorganic glasses at elevated temperatures. Figure (2-1b) is moderately ductile fracture after some necking [81].

Ductile fracture has two distinguished features, as the plastic deformation gives warning that fracture is imminent, allowing protective measures to be taken, second, extra strain energy is needed to induce ductile fracture in as much as ductile materials are normally tougher. Under the action of an imposed tensile stress, most metal alloys are ductile, whereas ceramics are especially brittle and polymers may show both types of fracture [82].

2.1.1.2 Brittle Fracture

The word (brittle) is related with a minimum of plastic deformation, i.e. with a brittle fracture the material fractures with very fast propagation of crack (propagates fast without increase in imposed stress) with very little or no plastic deformation [83,84].

For example, in some steel pieces, a series of V-shaped markings may form; near the center of the fracture cross section that point back toward the crack initiation site as shown in figure (2-2-A).



Figure (2-2): Brittle fracture surface, (A) very smooth mirror region near the origin of the fracture, with tear lines involving the remainder of the surface [14], (B) surfaces have lines or ridges that radiate from the origin of the crack into a fanlike pattern [78].

Other brittle fracture surfaces contain lines or ridges that radiate from the origin of the crack in a fanlike pattern as shown in figure (2-2-B). Often, both of these marking shapes will be sufficiently rough to be recognized with the naked eye. For very stiff and fine-grained metals, there will be no discernible fracture shape. Brittle fracture into amorphous materials, for example ceramic glasses, yields smooth surface and a relatively shiny [85].

2.1.1.3 Polymer Fracture

Large ranges of fracture modes are observed into polymers, depending on the underlying polymer structure and microstructure. Fracture in amorphous polymers tends to occur by craze creation due to the stretching of polymer microfibrils that give increase to gaps between polymer chains. These gaps are observed as micro-cracks or crazes when seen under a light microscope [86]. Three stages of cracking are typically observed as a crack advances through an amorphous polymer. The first stage, stage A in figure (2-3), includes crazing through the middle plane. This results in the creation of a mirror zone by the growing of voids along the craze. The second stage, stage B includes crack growing between the craze/matrix interfaces. This results in so-called mackerel patterns. Finally, the third stage, stage C includes cracking through craze bundles. This enhancing the creation of hackle bands, as cracking happens through bundles of crazes. The resulting coarse fracture surface has a misty look, and parabolic (hyperbolic marks) voids are noticed on the fracture surfaces as in figure (2-3). These voids are somewhat similar to those observed on the fracture surfaces of ductile metals in the exist of shear [77,87]. The fracture surface look and mechanisms for composites depend on the fracture characteristics of the matrix and reinforcement materials and on the effectiveness of the bonding between the two [77].



Figure (2-3): Stages of cracking into amorphous polymers, region A: crack advance by void creation, region B: crack advance along alternate craze-matrix interfaces, region C: crack advance through craze bundle to form hackle bands. [77].

The damage in composite materials may happen by Interfacial/interphase cracking and de-bonding, particle pull-out or fibril cracking [77]. The creation of cracks may be a compound fracture process, which strongly depends on the microstructure of a specific crystalline or amorphous solid, imposed loading and environment. The microstructure plays a very significant role in a fracture process because of dislocation motion, inclusions, precipitates, grain size and kind of phases making up the microstructure. All these microstructural features are defect and can act as fracture nuclei under negative conditions. For instance, brittle fracture is a low-energy process (low energy dissipation). On the other hand, ductile fracture is a high-energy process in which a large amount of energy dissipation is related with a large plastic deformation before crack instability happens. Consequently, slow crack growth happens due to strain hardening at the crack tip area [88,89].

Inorganic fillers particles are generally addition to polymer to improve the stiffness, if there is a strong interfacial strength this lead to rise the yield stress. In case of low or lost interfacial strength (adhesion), no-bonding and cavitation seems during loading. The micro-voids about the filler particles act as stress concentrators (like the elastomeric particles in rubber particle toughening) and can start local

42

yielding processes. According to particle distribution and particle size, several cases are often seen as shown in figure (2-4), [90]:

a- The basic effect is no-bonding/cavitation and local stress concentration.

b- Large particles create great voids with the disadvantage of void coalescence and construction of cracks of overcritical lengths.

c- Agglomerates of small particles can break, constructing sharp cracks.

d- Small, homogeneously distributed particles start local yielding among the particles/micro-voids.



Figure (2-4): Illustrations of particle-filled polymers and changed cases of local processes, depending on distribution and particle size [90].

2.1.1.4 Nanocomposites Fracture Toughness

Nanoparticles can overcome the infarct of traditional toughening kinds by simultaneously refining the toughness and strength of polymer (epoxy) without losing thermal or mechanical properties. The main toughening mechanisms due to nanoparticles-toughened matrices are; plastic deformation, crack pining of the matrix, filler induced crazing, (crack interaction with microstructure) and interfacial non-bonding/void growth by the rigid nanoparticles [91]. As a crack begins to propagate inside a composite material, the crack front meets particle fillers and bows out among the rigid particles as shown in figure (2-5), while still remaining pinned at all the locations where it has encountered the filler particles.



Figure (2-5): Crack pining for toughening of composite materials [92].

The pining process can create secondary cracks then combine after transient the particles. As the strain energy increases, local step fracture occurs and the pining point released leaving a (tail-like) feature on the fracture surface. Energy is absorbed and dissipated through the cracks-pining process, which leads to an increase in the fracture toughness of the material [92]. Crack deflection near or at particle/polymer interfaces is a source of energy dissipation through the crack propagation for particles filled polymer. As the crack front is approaching a polymer/particle interface, the crack can tilt and change direction when it encounters the rigid particles and passes about them. This process is shown in figure (2-6) such deflection cause a continuous change in the local stress state from mode I (opening) to mixed-mode, e.g. mode I/II (tensile/in-plane shear) in the case that the crack tilts and mode I/III (tensile/out of plane-shear) if the crack twists. To propagate a crack below mixed mode conditions needs a higher driving force than in pure mode I, which consequences in a higher fracture toughness of the material [92].



Figure (2-6): Schematic of crack deflection mechanism [92].

2.1.2 Stress-Strain Behavior

The stress-strain performance is the degree to which a structure deforms or a strain depend on the value of an applied stress. For most metals that are stressed in tension at relatively low levels, stress and strain are proportional to each other through the relationship [76]:

This is called Hooke's law, when (E) the modulus of elasticity (Young's modulus), where strain (ϵ) and stress (σ) are given by:

Where A: is the area (m²) of a plane, F (N): is the force, the elongation $\Delta L = L-L_o$ and L, L_o: the instantaneous and original length. Deformation in which stress and strain are proportional is named elastic deformation; a plot of stress (ordinate) vs. strain (abscissa) results in a linear relationship, elastic deformation as illustrated in figure (2-7A). The slope of this linear share corresponds to the modulus of elasticity (E). Elastic deformation is nonpermanent, which means that where the imposed load released, the piece returns to its cardinally shape [76,77,93].



Figure (2-7): Schematic stress–strain diagram, A-linear elastic deformation, B-nonlinear elastic behavior, C, D-plastic deformations, E-Ultimate stress, F-Stress at failure, where region I is linear elastic deformation (brittle behavior) and region II is plastic deformation (ductile behavior). [93].

There are some materials (e.g., many polymers) for which this elastic portion of the stress–strain curve is not linear as shown in figure (2-7B), hence, it is not possible to determine a modulus of elasticity as described above. For this nonlinear behavior, either tangent or secant modulus is normally used. As the material is deformed beyond this point (B) the proportional limit, the stress is no longer proportional to strain (Hooke's law, equation (2-1), ceases to be valid), and permanent, non-recoverable, or plastic deformation occurs as shown in figure (2-7 C, D). The transition from elastic (region I – brittle behavior) to plastic (region II – ductile behavior) is a gradual one for most metals, some curvature results at the onset of plastic deformation, which increases more rapidly with increasing stress [85,94].

2.1.3 Three-Point Bending

The three-point bending test is shown schematically in figure (2-8), a flat rectangular sample is simply supported close to its ends and centrally loaded in three-point bending [94]. The three points bending flexural test provides values for the modulus of elasticity (E_f), flexural stress (σ_f), flexural strain (ϵ_f) and the flexural stress-strain response of the material [95].



Figure (2-8): (a) The three-point bend test, (b) The deflection and the thickness (d) obtained by bending [94].

It is assumed that the material properties are uniform through thickness. Under these circumstances (force distribution, uniform material) the usual stress varies linearly from a maximum in compression on one surface to an equal maximum in tension on the other surface, when the imposed force at the sample midpoint cause in bending this constitutes a bending moment (M) close to sample ends while (M_m) is the moment of resistance as shown in figure (2-9) [74].

Where:



Figure (2-9): Three-point bending test setup and force distribution [74].

For rectangular beam the flexural stress (σ_f) or modulus of rupture, describes the materials strength [94]:

$$\sigma_{\rm f} = \frac{M}{M_{\rm m}} \qquad (2-6)$$

$$\sigma_{\rm f} = \frac{3FL}{2hw^2} \qquad (2-7)$$

The modulus of elasticity in bending, the Young modulus in bending or the flexural modulus calculated in the elastic region of figure (2-7):

$$E_f = \frac{L^3 S}{4hw^3}$$
 (2-8)

Where S: is the slope of the straight-line portion of force-deflection curve [74].

2.1.4 Impact Strength

Impact strength refers to ability of material to absorb the energy. The measurement of impact strength is most commonly made by the izod or charpy impact test as shown in figure (2-10). The principle of both methods is to strike a small bar of polymer with a heavy pendulum swing. In the izod tests the bar is held vertically by gripping one end in a vice and the other free end is struck by the pendulum. In the charpy test the bar is supported at its ends in a horizontal plan
and strike in the middle by the pendulum, and the impact bars are normally notched, the impact-strength test are carried out at very high strain rates. The weight end of the pendulum is raised to a fixed height (h) and is then released. The maximum displacement is noted down as (h') the difference in height (h-h'), the energy absorbed at fracture (E) can be obtained by simply calculating the difference in potential energy of the pendulum before and after the test such as:

$$E = m g (h-h')$$
(2-9)

Where E: the impact energy, m: is the mass of pendulum and g: is the gravitational acceleration.

The impact strength is calculated from the following relation:

$$I.S = U (Joule)/A (m^2)$$
(2-10)

Where I.S: is impact strength, U: is energy of fracture and A: is area of cross section.

The geometry of (55 mm) long, standard charpy test specimen is given in figure (2-10).



Figure (2-10): Apparatus for impact testing of materials, specimen and loading configuration for a) charpy pendulum and b) izod pendulum. [96].

If the dimensions of specimens are maintained as indicated in standards, notched-bar impact test results are affected by the lattice type of materials, testing temperature, thermo-mechanical history, chemical composition of materials and degree of strain hardening [97].

2.1.5 Hardness

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching and abrasion. Hardness techniques are a small indenter that is forced into the surface of the material, to be tested, under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured hardness test are carried out frequently. There are a few different hardness tests: Rockwell (HRC), Brinell (HB), Vickers (HV) and Shore (HS) [96].

Shore hardness is a measure of the resistance of a material to penetration of a spring-loaded needle-like indenter. Shore A scale is used for testing soft elastomers (rubbers) and other soft polymers. Hardness of hard elastomers and most other polymer materials (thermoplastics, thermosets) is measured by shore D scale. Shore hardness is tested with an instrument called durometer. Durometer utilizes an indenter loaded by a calibrated spring. The measured hardness is determined by the penetration depth of the indenter under the load. Two different indenters as shown in figure (2-11) and two different spring loads are used for two shore scales (A and D). The loading forces of shore A: 1.812 lb (822 g), shore D: 10 lb (4536 g) [98].



Figure (2-11): Two different indenters of durometer hardness test [98].

2.2 Physical Properties

2.2.1 Electrical properties

2.2.1.1 Dielectric Constant

The dielectric constant relates to the permittivity of the material (symbol use here ε). The permittivity indicates the ability of a material to polarize in response to an imposed field. It is the ratio of the permittivity of the dielectric to the permittivity of a vacuum. Physically it means the greater the polarization developed by a material in an imposed field of given strength, the greater the dielectric constant will be [99]. Polymers and the atoms that create them up have their electrons tightly bound to the central long chain and side groups during covalent bonding. Covalent bonding marks it much more difficult for most conventional polymers to support the movement of electrons and so they act as insulators [100].

2.2.1.2 Dielectric Polarization

When a dielectric material placed in static electric field (E), electric charges do not flow through the material, but only slightly shift (creating electric dipoles) from their average equilibrium positions producing electric polarization (P) also can be thought of as charge redistribution into a material affected by an external electric field. The electric moment obtained by an atom or a molecule under the effect of an electric field is proportional to the imposed field. The relation between polarization and the electric field is given by [101]:

$$P = \chi' \varepsilon_{\circ} E \qquad \dots \dots \dots (2-11)$$

Where χ' : is the electrical susceptibility of material, ε' : is the permittivity of the material and ε_{\circ} : the permittivity of vacuum. There are four basic kinds of electric polarization: electronic polarization, ionic or atomic polarization, dipolar polarization and space charge or interface polarization. The total polarization of an arbitrary dielectric material is contributing of all kinds of polarization; as shown in figure (2-12) [102]:

a- Electronic Polarization

The electric field causes deformation or translation of the originally symmetrical distribution of the electron clouds of atoms or molecules. This is basically the displacement of the outer electron clouds with respect to the internal positive atomic cores [103]. This effect is shared to all materials. This polarization effect is small, despite the vast number of atoms within the material, since the moment arm of the dipoles is very short, which maybe comprises only a small fraction of an angstrom [104].

b- Atomic or Ionic Polarization

The electric field makes the ions or atoms of a polyatomic molecule to be displaced relative to each other. This is essentially the distortion of the normal



lattice vibration, and this is why it is sometimes denoted to as vibrational polarization. Ionic displacement is common in ceramic material [103].

Figure (2-12): Basic kinds of electric polarization: (a) electronic polarization, (b) atomic or ionic polarization, (c) dipolar polarization and (d) interface or space charge polarization. [105].

c- Dipolar polarization

This polarization occurs only in materials consisting of particles or molecules with a permanent dipole moment. The electric field causes the reorientation of the dipoles toward the direction of the field [104].

d- Space Charge Polarization (Interface)

Interfacial polarization or the space charge is produced by the separation of movable positively and negatively charged particles under an imposed field, which form negative and positive space charges in the bulk of the material or at the interfaces between different materials. These space charges, in turn, modify the field distribution. This occurs mainly in polycrystalline solids or amorphous or in materials consisting of traps [103].

2.2.1.3 Electric Polarization in Frequency Changing Electric Fields

In the frequency-domain method, was mainly measured the dielectric constant at different frequencies of alternating excitation fields. Every kind of polarization takes time to done; so, the degree of the total polarization depends on the time difference of the electric field (frequency). The relation between the polarization (P) and electric field (E) is given by equation (2-11) still holds, but the susceptibility (χ) is now a complex number [106]:

Where χ' : indicates its real part (given in equation (2-12)) and χ'' : its imaginary parts, taking account of equation (2.11 – 2.14) we find:

$$\chi'' = \varepsilon^{''} \qquad \dots \dots \dots \dots (2-15)$$

The dielectric constant (ε_r) (the relative permittivity of material) defined as the ratio of the static field strength of a vacuum to that in the material at the same distribution of charge. In (m.k.s.) system the dielectric constant (the permittivity of vacuum) (ε_o) of free space is (8.854*x*10⁻¹²) Farad per meter and also and may be defined as the measure of a material's ability to store electric charge equal to [107]:

Where ε : is the permittivity of the material which will be greater in magnitude than ε_{\circ} , and relative permittivity is greater than unity [75]. When a time-varying electric field is applied the complex dielectric constant (ε^*) appear which is introduced to

allow for dielectric losses due to the friction accompanying polarization and orientation of electric dipoles. This may be written as:

Where ε_r : is called the dielectric constant (relative permittivity (real part)) and ε_r' : is called the loss factor. The dielectric constant depends strongly on the frequency of the alternating electric field or the rate of the change of the time-varying field. Dielectric constant (ε_r), the loss factor (ε_r') and tangent of loss angle (tan δ) calculated according to the following relations [108]:

Where d: is a thickness of specimen, R: is a resistance of specimen, A: is an effective area, C: is a capacitance and ε_{\circ} : is a permittivity of free space. Information about conduction mechanism of materials can found from (A.C) electrical conductivity. A frequency dependence of (A.C) electrical conductivity ($\sigma_{A.C}(\omega)$) has been observed in many amorphous semiconductors and insulators both inorganic and polymeric materials, the empirical relation for the frequency dependence (A.C) electrical conductivity is given by [109]:

Where s: is the exponential factor, it is usually less than or equal to one and w: is the angular frequency (w = 2π f) and the exponential factor equation is:

$$s = \frac{d[Ln(\sigma)]}{d[Ln(\omega)]} \qquad \dots \dots \dots (2-22)$$

have the following relations with (A.C) electrical conductivity according to the following relations [108,110]:

$$\sigma = \frac{d}{RA} \qquad \dots \dots \dots (2-23)$$
$$\varepsilon_{r'} = \frac{d}{\omega R A} = \frac{\sigma_{a.c}}{\omega \varepsilon_{\circ}} \qquad \dots \dots \dots (2-24)$$

2.2.1.4 The Influence of Frequency on Dielectric Loss.

The variation of the dielectric constant with frequency is similar to the difference of polarizability and polarization. At low frequencies of the order of a few (Hz) the dielectric constant is made up of contributions from electronic, atomic and space charge polarization [111]. When measurements are carried out as a function of frequency, the space charge polarization ends after a certain frequency and the dielectric constant becomes frequency independent. The frequency beyond which the variation ends may fall in the certain range. The frequency-independent value as in the true static dielectric constant [112].

By measuring the dielectric constant as a function of frequency, one can discrete the different polarization components. Each polarization mechanism has a bounding properties frequency. Electrons have very small mass and are therefore able to follow high frequency fields up during the optical range. Ions are a thousand times heavier but continue to follow fields up to the infrared range. Molecules-especially those in liquids and solids are heavier yet and are severely constraining by their surroundings. Most rotational effects, like those in water, are bounded to microwave frequencies. Space charge effects are often in the kilohertz range or even lower frequency has a significant effect on the polarization mechanisms of a dielectric. When the frequency of the imposed field is quite large as compared to the inverse of the relaxation time for a particular polarization process, the contribution of that process to the polarizability is negligible. As relaxation time is maximum for the space charge polarization, the space polarization vanishes first followed by dipolar, ionic and electronic contributions. Figure (2-13) shows a typical frequency spectrum of a dielectric containing all four kinds of polarization [108,111].



Figure (2-13): The frequency dependence of polarizability showing some contribution mechanisms [112].

2.2.1.5 Dielectric Properties of Nanocomposites

The polymer matrix composites are classified as insulators. The electrical response for polymer matrix nanocomposites refers to their conductivity and dielectric performance. Since the primary electrical character of polymers is insulating, polymer composites seem to be dielectrics, (which can be polarized under the effect of an external electric field). Considering the character of the employed nanofiller, polymer nanocomposites categorizes in two majors classified: first the insulating matrix-dielectric reinforcing phase and second the insulating matrix-conductive reinforcing phase. The nature of the nanofiller will defer in

kinds, shape, and properties where it could be organic, inorganic, conductive, insulation, spherical, non-spherical [108].

2.2.1.6 The Influence of Nanoparticles and Interaction Zones

In considering the influence of the insertion of nanoparticles in an insulator there are two essential factors to consider. First, the effect of nanoparticles occurred on the physical and chemical structure of the material. Second, how the nanoparticles changed the electrical properties of the surrounding material. The percolation effects characterized by increasing in electrical conductivity by several order of magnitude. This interaction zone may overlap giving rise to effects related with percolation through the interaction zone as shown in figure (2-14) [92,108].



Figure (2-14): Illustration of interaction zones for (a) a microparticles and (b) an assembly of nanoparticles. [92].

2.2.2 Thermal Properties

2.2.2.1 Thermal Conductivity

The thermal conductivity is the property of a material that indicates its ability to conduct heat. This physical constant is defined as the amount of heat that passes during a unit cube of a material in a unit of time, when the variance in temperature between the opposite sides of the cube is (1K) along the direction of the heat flow. Both parameters are related by:

$$Q = -k A \frac{(T_1 - T_2)}{x} \qquad \dots \dots \dots (2-26)$$

Where Q: is the heat flux (W), k: is the thermal conductivity coefficient (W/m-K), A: is the cross-sectional area (m²), T_1 - T_2 : it is the difference in temperature (K) and x: is the thickness of the sample (m) [113].

The measure of thermal conductivity coefficient depends on the nature of the substance being examined. Lee has determined the conductivity of small thin disc of material by a method, which is applicable over a wide range of temperatures [99]. The arrangement Lee's disc is shown in figure (2-15).



Figure (2-15): Schematic diagram of Lee's disc [32].

The sample is placed between two brass discs (A) and (B), and the electric heater between (B) and a third brass discs (C). The temperatures of all the brass discs are measured by thermometer. When the discs have been assembled, they were varnished to give them the same emissivity, and the whole apparatus is suspended in an enclosure of constant temperature. The amount of the heat loss to the surrounding can be estimated as [114]:

 $q_A = h (\pi r^2 + 2\pi r d_A) T_A$ (2-27)

Where h: Heat transfer coefficient in $(W/m^2. K)$.

r: Radius of the specimen disc in (m).

d_A: Thickness of the disc (A) equal to (12.25 mm).

T_A: Temperature measured at disc (A) in (K).

The amount of the heat gained by disc (S) can be determined as follows:

$$q = h (\pi r^{2} + 2\pi r d_{A}) T_{A} + h (2\pi r d_{s}) (T_{A} + T_{B}) \qquad \dots \dots \dots \dots (2-28)$$

Where d_S: Thickness of disc (sample) equal to (6 mm).

T_B: Temperature measured at disc (B) in (K).

The amount of heat passed through disc (sample) is:

$$q = k\pi r^2 \frac{T_A + T_B}{d_s}$$
(2-29)

Then thermal conductivity (W/m.K) is deduced using the following relationship:

Finally, the heat transfer coefficient is obtained from the following equation [115]:

$$h = \frac{IV}{\pi r^2 (T_B + T_A) + 2\pi r [d_A T_A + 0.5 d_s (T_A + T_B) + d_A T_B + T_C d_C} \qquad \dots \dots \dots (2.31)$$

Where:

I V: Rate of energy supply in (Amp. – Volt).

d_C: Thickness of disc (C) in (mm).

T_C: Temperature measured at disc (C) in (K).

2.2.2.2 Thermal conductivity of polymers

Polymer materials show a weak thermal conductivity. Thermal conductivities of insulating polymer materials are generally (1-3) orders lesser than those of ceramics and metals. Due to the chain-like structure of polymers, the heat capacity involves of the contribution of two mechanisms: (a) lattice vibrations and (b) characteristic vibrations, which originate from inner motions of the repeating unit. The lattice vibrations are acoustic vibrations, which give the main contribution to the thermal conductivity at low temperatures. The characteristic vibrations of the side groups of the polymer chains are optical vibrations, which become visible at temperatures above (100 K) [114]. For polymers reinforced with different kinds of fillers this is even more important. Enhanced thermal conductivity in polymers may be achieved either by molecular orientation or by the addition of highly heat conductive fillers [116,117]. There are many factors may affect the thermal conductivity of polymers: Temperature, pressure, density of the polymer, orientation of chain segments, crystal structure, the degree of crystallinity and many other. The thermal conductivity of filled polymers is primarily determined by the kind and amount of fillers used. The thermal properties of the filler, the size, shape, orientation of filler particles or fibers in polymer matrix and the percentage of fillers are all important factors that determine the thermal conductivity of reinforced polymers [118].

2.2.3 Moisture Absorption

Water enters the composite by diffusion through the resin and by capillary action along the fiber matrix interface. The surface damage and cracks produced as a result of weathering further facilitate the entrance of water. The effect of water on the resin which causes swelling and plasticization-hydrolysis of resin is not considered to be an important process under the conditions encountered outdoors. In the epoxies there are three important functional groups which can associate with water, the hydroxyl groups formed when curing agents add across epoxide groups, the phenol in ether groups which are present in all bisphenol (A) or novolac based resins and the amino groups of the curing agents [119,120].

The two main types of basic moisture conditioning are; fixed conditioning, where a test specimen is exposed to a conditioning environment for a specified time, and equilibrium conditioning, where a specimen is exposed until the material reaches equilibrium with the conditioning environmental. The rate of moisture uptake is fairly rapid in early stages of conditioning with the rate of moisture uptake decreasing with time as shown in figure (2-16). It is therefore necessary to make frequent weigh measurements in the early stages (3-4 measurements on day one) followed by at least two readings per a day for the remainder of the first week. At least one reading per day is required for second week, followed by a gradual decrease in frequency as the rate of weight gain diminishes. It is recommended that weighing be carried at approximately equal intervals of (time)^{1/2}. The percentage uptake of water by weight (M) can be determined as follows:

Where the wet and dry weights are denoted by: W_{wet} and W_{dry} [121,122].







3.1 Introduction

This chapter studied the properties of the materials and the preparation methods of the hybrid matrix of composite materials which included epoxy resins, phenol formaldehyde resins. Nanocomposites filler were (MgO and ZrO) with reinforcement fibers (Glass, Carbon, Kevlar). Mechanical properties such as (tensile, bending, impact and hardness tests) and physical properties such as (thermal, dielectrical and absorption tests). Measurement techniques were described in this chapter as shown in figure (3-1).

3.2 The Raw Materials

The raw materials used to prepare the specimens of composite materials are:

1. Epoxy Resin (ER)

Epoxy resin as a matrix and it is a two component, component (A) used sikadur (52LP) contains of solvent free, low viscosity injection.liquid, based on high strength epoxy resin and hardener component (B) from sikadur (52LP) as shown in figure (3-2). The mixing ratio for resin component (A) and hardener component (B) is (A: B = 2:1) parts by weight and pot life (2 Kg) at (30) minute of (L.P.) type and viscosity (130 mPa.s) at (30°C).

2. Phenol Formaldehyde Resin (PF)

Phenol formaldehyde resin is acidic catalyst with poly-condensation of phenol and formaldehyde. This resin was produced in the presence of acidic catalyst with poly-condensation of phenol and formaldehyde. Made by mining industries company $\$ the ministry of industry $\$ Iraq as shown in figure (3-3). Table (3-1) shows the properties of resin materials used in the preparation of samples:



Figure (3-1): The step experimental work of the research



Figure (3-2): (a) Epoxy resin component (A) sikadur (52LP), (b) Hardener component (B) from sikadur (52 LP).



Figure (3-3): Phenol formaldehyde resin.

Table (3-1): Epoxy and phenol resins materials and some of their properties.

Specification	Epoxy	Phenol Formaldehyde
Appearance	Comp. (A): yellowish Comp. (B): brownish	Pale brown liquid
Specific gravity	$(1.11 - 1.18 \text{ g/cm}^3)$	$(1.15 - 1.20 \text{ g/cm}^3)$
pН	Not defined	(8.0 - 8.5)
Viscosity at (25°C)	(250 mPa.s)	(150 – 350 mPa.s)
Density (20°C)	Comp. (A/B:1.1) (Kg/l) (mixed)	(1.21 Kg/l)
Shelf-life at (25°C)	(12 month)	(45) days from the manufacture
Pot life (2 kg) at (20 °C)	(60 min)	(120 min)
Mechanical	Compressive = 53 N/mm^2	Compressive = 66 N/mm^2
strength	$Flexural = 50 N/mm^2$	$Flexural = 59 N/mm^2$
at (20 °C, 10 days)	Tensile = 25 N/mm^2	Tensile = 48 N/mm^2
Coefficient of	(89x16 ^{.6} m) at (-20 to	(99x16 ^{.6} m) at (-10 to
thermal expansion	60 °C)	60 °C)

3. The Fibers Reinforcement Materials

The types of fibers used to reinforce composite materials are:

1. Glass fibers (E.glass fibers, glass fibers biaxial fabric 0:90), the basis of textilegrade glass fibers is silica (SiO₂).

2. Carbon fibers precursors for the production of carbon fibers include polyacrylonitrile (PAN), isotropic pitch, mesophase pitch and regenerated cellulose, among others.

3. Kevlar fibers (kevlar.49), kevlar fibers used as thermoplastic matrix are:

(a). P₁-thermoplastic, (Styrene Acrylonitrile), (b). P₂-astalac, (ABS) (acrylonitrile butadiene styrene, 2029.2) and (c). P₃-dowlex polyethylene resins.

Types and properties of fibers used in this work are shown in figure (3-4) and table (3-2).



Figure (3-4): (a) E-glass fibers, (b) Carbon fibers and (c) Kevlar-49 fibers.

Table (3-2):	Fiber	materials	and	some	of	their	properties.
--------------	-------	-----------	-----	------	----	-------	-------------

Samples	Tensile Strength	Compressive Strength	Elastic Modulus (GPa)	Density (g/cm ³)
E. glass fibers	3445 (MPa)	1080 (MPa)	73	2.58
Carbon fibers	3–7 (GPa)	1–3 (GPa)	200–935	1.75-2.20
Kevlar fibers	2757.9 (MPa)	517.1 (MPa)	151.7	1.467

4. Nano Particles Materials

Two types of nanoparticles (Zirconium oxide (ZrO_2) and Magnesium oxide (MgO)) were used and their properties as shown in figure (3-5) and table (3-3).



Figure (3-5): (a) Zirconium oxide nanoparticles and (b) Magnesium oxide nanoparticles.

Specification	ZrO_2	MgO
Matarial nama	Zirconium oxide (zirconia),	Magnesium oxide
	nanoparticles	(magnesia), nanoparticles
Appearance	Solid, white powder	White powder
Particle size	(40.50) nm	\leq 50 nm
Density g/cm ³	5.89	3.58
Purity	99%	99%
Recommend dosage	0.8%.9.6%	0.5%.7.5%
Specific surface area	$(15.40) \text{ m}^2/\text{g}$	$(25.1) \text{ m}^2/\text{g}$

Table (3-3): Properties of the nanoparticles.

3.3 Sample Preparation

The most basic fabrication method for composites is hand lay-up as shown in figure (3-6), which consists of laying dry plies or prepreg plies by hand or a tool to form a laminate stack. The casting mold consists of glass plates with dimensions (200x200x4 mm) and under the casting mold putted dry plies or prepreg plies to prevent adhesion of the composite material as shown in figure (3-7). All the test specimens are finished by abrading the edges on a fine carborundum paper.



Figure (3-6): Schematic illustration of hand-layup.



Figure (3-7): The casting mold consists of glass plates with dimensions (200 x 200 x 4 mm).

Neat epoxy preparation, firstly epoxy resin and hardener are weighted 2:1 mixing ratio, and manually mixed then epoxy resin and hardener were mixed by magnetic stirrer at (800 rpm) for (15 minutes) at room temperature to obtain a good homogeneity between epoxy resin and hardener and casting the solution with the mold of glass plates until neat epoxy dries fully before specimens cutting. Secondly, epoxy risen and phenol resin prepared by weight for suitable mixing ratio and mixed by magnetic stirrer at (800 rpm) for (15 minutes) and add the hardener 2:1 mixing ratio as shown in table (3-4), and casting the solution with the mold of glass plates. The mixture was cured at room temperature until resin blend dry fully before specimens cutting. The first layer of fibers was laid and resin blend spread uniformly over it.

Sample	Mixing Ratio of Epoxy	Mixing Ratio of Phenol
	Resin	Resin
ER	100%	0%
95% ER/5% PF	95%	5%
90% ER/10% PF	90%	10%
85% ER/15% PF	85%	15%
80% ER/20% PF	80%	20%
70% ER/30% PF	70%	30%
60% ER/40% PF	60%	40%
50% ER/50% PF	50%	50%

Table (3-4): Mixing ratio of epoxy resin and phenol resin.

After the second layer, to enhance wetting and impregnation, a teethed steel roller was used to roll over the fabric before applying resin blend. The same procedures are used with nanoparticle samples. The mixture was cured at room temperature until the composite materials dry fully and it depending on the type of hybrid composite and the weight fraction of the reinforcing materials as shown in table (3-5) and finally removed from the mold to get a fine finished composite laminate. All these procedures should be in the laboratory free from dust, clean and dry with precautions taken by wearing protective gloves, goggles and procedure mask at good ventilated room.

3.4 Specimens Cutting

The composite materials were cut according to American society for testing and materials (ASTM) to prepare specimens for mechanical and physical testes. Specimens cutting by computer numerical control (CNC) machine containing a rotary head with a drill piece used for cutting various hard materials as shown in figure (3-8).

Symbols of Samples	Composite Materials
ER/PF/ZrO	95% Epoxy / 5% Phenol / 1% ZrO ₂
ER/PF/MgO	95% Epoxy / 5% Phenol / 1% MgO
ER/PF/GF	95% Epoxy / 5% Phenol / 1% Glass fibers
ER/PF/CF	95% Epoxy / 5% Phenol / 1% Carbon fibers
ER/PF/KF	95% Epoxy / 5% Phenol / 1% Kevlar fibers
ER/PF/ZrO/GF	95% Epoxy / 5% Phenol / 1% ZrO ₂ / 1% Glass fibers
ER/PF/ZrO/CF	95% Epoxy / 5% Phenol / 1% ZrO ₂ / 1% Carbon fibers
ER/PF/ZrO/KF	95% Epoxy / 5% Phenol/ 1% ZrO ₂ / 1% Kevlar fibers
ER/PF/MgO/GF	95% Epoxy / 5% Phenol / 1% MgO/ 1% Glass fibers
ER/PF/MgO/CF	95% Epoxy / 5% Phenol / 1% MgO/ 1% Carbon fibers
ER/PF/MgO/KF	95% Epoxy / 5% Phenol/ 1% MgO / 1% Kevlar fibers

Table (3-5): Mixing ratio of composite materials



Figure (3-8): (a) Rotary head of (CNC) machine, (b) Specimens cutting by (CNC) machine.

3.5 Mechanical Tests Samples

3.5.1 Tensile Test Samples

The tensile test is carried out by (CNC) machine accordance with (ASTM) (standard test method for tensile properties of plastics: D 638, 02 a) at room temperature as shown in table (3-6).

Symbol of Samples	Tensile Tests Sample	Symbol of Sample	Tensile Test sample
ER		ER/PF/CF	
95% ER/ 5% PF		ER/PF/KF	
90% ER/ 10% PF		ER/PF/ZrO/ GF	
85% ER/ 15% PF		ER/PF/ZrO/ CF	
80% ER/ 20% PF		ER/PF/ZrO/ KF	
ER/PF/ ZrO		ER/PF/MgO /GF	
ER/PF/ MgO		ER/PF/MgO /CF	
ER/PF/ GF		ER/PF/MgO /KF	

 Table (3-6): Tensile test samples of different types of composite materials.

3.5.2 Bending Test Samples

The final samples shape prepared by (CNC) machine for bending test are identical to the specification of (ASTM, D 790) at room temperature as shown in table (3-7).

Symbol of Sample	Bending Test Sample	Symbol of Sample	Bending Test Sample
ER		ER/PF/CF	
95%ER/ 5%PF		ER/PF/KF	
90%ER/ 10%PF		ER/PF/ ZrO/GF	
85%ER/ 15%PF		ER/PF/ ZrO/CF	
80%ER/ 20%PF		ER/PF/ ZrO/KF	
ER/PF/ ZrO		ER/PF/ MgO/GF	
ER/PF/ MgO		ER/PF/ MgO/CF	
ER/PF/GF		ER/PF/ MgO/KF	

Table (3-7): Bending	test samples of	f different types (of composite materials
----------------------	-----------------	---------------------	------------------------

3.5.3 Impact Test Samples

The Charpy impact pendulum specimen with standard (ASTM: D 6110.10) at room temperature and were cut by (CNC) machine as shown in table (3-8).

Table (3-8): Impact test samples of different types of composite materials.

Symbol of Sample	Impact Test Sample	Symbol of Sample	Impact Test Sample
ER		ER/PF/CF	
95%ER/ 5%PF		ER/PF/KF	
90%ER/ 10%PF	A State State	ER/PF/ZrO/GF	
85%ER/ 15%PF		ER/PF/ZrO/CF	
80%ER/ 20%PF		ER/PF/ZrO/KF	
ER/PF/ ZrO		ER/PF/MgO/ GF	
ER/PF/ MgO		ER/PF/MgO/ CF	
ER/PF/GF		ER/PF/MgO/ KF	

3.5.4 Hardness Test Samples

The hardness test is carried out by (CNC) machine using for shore hardness (D) test according to (ASTM: D 2240) at room temperature. The hardness of test specimens was found by taking seven reading from several points of the specimens and calculate the average of them.

3.6 Physical Tests Samples

3.6.1 Thermal Conductivity Test Samples

Thermal conductivity test is carried out by (CNC) machine for Lee's disc test and according to (ASTM: E 285) at room temperature as shown in the table (3-9).

3.6.2 Dielectric Test Samples

The final samples shape prepared by (CNC) machine for dielectrical test identical to the specification of (ASTM: D 150) at room temperature as shown in table (3-10).

3.6.3 Water Absorption Test Samples

This test was performed by (CNC) machine for immersion in water and according to water absorption (ASTM: D 570) as shown in table (3-11).

3.7 Technical Testing Procedures

There are many tests to measure the spacemens for both mechanical and physical tests of composite materials under investigation. The following tests are:

3.7.1 Mechanical Tests

3.7.1.1 Tensile Test

The tensile test is carried out in accordance with (ASTM), standard test method for tensile properties of plastics–D638.02a in this work.

Symbol of Sample	Thermal Conductivity Test Sample	Symbol of Sample	Thermal Conductivity Tests Sample
ER		ER/PF/CF	
95%ER/5%PF		ER/PF/KF	
90%ER/10%PF		ER/PF/ZrO/GF	
85%ER/15%PF		ER/PF/ZrO/CF	
80%ER/20%PF		ER/PF/ZrO/KF	
ER/PF/ZrO		ER/PF/MgO/GF	
ER/PF/MgO		ER/PF/MgO/CF	
ER/PF/GF		ER/PF/MgO/KF	

Table (3-9): Thermal conductivity test samples of different types of composite materials.

Symbol of	Dielectric Test	Symbols of	Dielectrical tests
Sample	Sample	samples	samples
ER		ER/PF/CF	
95%ER/5%PF		ER/PF/KF	
90%ER/10%PF		ER/PF/ZrO/GF	
85%ER/15%PF		ER/PF/ZrO/CF	
80%ER/20%PF		ER/PF/ZrO/KF	
ER/PF/ZrO		ER/PF/MgO/GF	
ER/PF/MgO		ER/PF/MgO/CF	
ER/PF/GF		ER/PF/MgO/KF	

 Table (3-10): Dielectric test samples of different types of composite materials.

Symbol of	Water Absorption	Symbols of	Water Absorption
Sample	Tests Sample	Sample	Tests Samples
ER		ER/PF/CF	
95%ER/5%PF		ER/PF/KF	
90%ER/10%PF		ER/PF/ZrO/GF	
85%ER/15%PF		ER/PF/ZrO/CF	
80%ER/20%PF		ER/PF/ZrO/KF	
ER/PF/ZrO		ER/PF/MgO/GF	
ER/PF/MgO		ER/PF/MgO/CF	
ER/PF/GF		ER/PF/MgO/KF	

 Table (3-11): Water absorption test samples of different types of composite materials.

The type of equipment used was (tinius olsen, U.K., model (HKT 50 kN). The velocity of pulling was (1mm/min) and by utilization of the connected graphic plotter. Tensile load is applied at a rate of (20 Kg) as shown in figure (3-9).

The relationship would be (stress-strain). Tensile strength was calculated electronically via the software of the testing machine curve to calculate the ultimate tensile strength (Rm) for the specimens. The maximum (peak) load (F max) is the greatest force which the test piece withstands during the test and calculate:



Figure (3-9): Tensile test equipment by tinius olsen, U.K., model (HKT).

3.7.1.2 Bending Test

The bending test is carried out in accordance with using instron universal testing machine (tinius olsen, U.K., model (HKT 50 KN)), using the 3-point bending method according to (ASTM D 790) as shown in figure (3-10). The specimens were tested at a crosshead speed of (0.5 mm/min). The specimens are cut into rectangular sizes with (4 mm) thickness, (10 mm) width and (100 mm) length. The bending strength of a material is expressed as the stress on the outermost fibers of a specimen, at the instant of failure. In a conventional test, the flexural strength is the stress on the surface of the specimen at failure, which should be accompanied by the breaking of fibers, rather than interlaminar shear.



Figure (3-10): Bending test equipment by tinius olsen, U.K., model (HKT).

The strength is calculated using the maximum bending moment, flexural strength (σ_f Mpa) is calculated according to equation (2-7). In each of the specifications, the flexural modulus is defined, such that for a three-point bending test it is calculated according to equation (2-8).

3.7.1.3 Impact Test Equipment

This test consists mainly of pendulum and energy gauge (XJU.22 pendulum impact tester, time testing machines) as shown in figure (3-11). Charpy impact test consists of standard test piece that would be broken with one flow of a swinging hammer.



Figure (3-11): Pendulum impact tester equipment, time testing machines.

The test piece is supported at both ends in a way that the hammer strikes it at the middle. The testing method includes lifting of the pendulum to its maximum height and fixing it firmly. The specimen is fixed in its pertaining place and then the energy gauge is initialized (on zero position), after that the pendulum is freed whereas its potential energy would be changed to kinetic energy. Some of this kinetic energy is utilized to fracture the specimen, while the energy gauge reads the value of fracture energy (U) for the sample under test. Impact strength energy by (Joule) is calculated by applying the equation (2.10).

3.7.1.4 Hardness Test

The hardness test is carried out in accordance with elcometer (din iso 7619 d 2240) shore (D) hardness tester, germany as shown in figure (3-12).



Figure (3-12): Elcometer shore (D) hardness equipment.

Durometers are capable of measuring medium to very hard and highly resistive materials. The material under test was at minimum (4 mm) thick.

3.7.2 Physical Tests

3.7.2.1 Thermal Conductivity Test

Lee's disk system manufactured by Griffin and George, Ltd., was used to calculate thermal conductivity (k) of specimens as shown in figure (3-13),

(Appendix C) consists of four identical copper discs with (40 mm) in diameter and (12.25 mm) thickness. The specimens (40 mm) and different thickness were placed between the two copper disks (A, B). Heat is supplied with a (D.C.) power supply (V) (6 Volt) and the current (I) is measured (0.4 Amperes), and then the rate of supply energy is (IV).



Figure (3-13): (a) Schematic of lee's disc and (b) Lee's disc equipment.

The time considered for the current passing through the lee's disk was (20 min) for all specimens also, the temperature related to each copper disk was recorded before and after current passing, then equations (2.30) and (2.31) are employed in order to calculate thermal conductivity at room temperature.

3.7.2.2 Dielectric Test

(LCR) meter is used to measure the inductance (L), capacitance (C), resistance (R), impedance, loss factor 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 (4294 A) an American origin as shown in figure (3-14), its range of frequency (100 Hz .1 MHz). The dielectric constant, the loss factor and tangent of loss angle are calculated according to are equations (2.18), (2.19) and (2.20).



Figure (3-14): LCR meter equipment.

3.7.2.3 Water Absorption Test

The water absorption test of hybrid composite materials reinforced by fibers and nanoparticles was done as per (ASTM 570) by immersion in distilled water at room temperature as shown in figure (3-15). The samples were taken out periodically and after wiping out the water from the surface of the sample weighted immediately using a precise balance machine to find out the content of water absorbed. The specimens were weighed regularly at (24, 48, 72, 96, 120, 144, 168, 192, 216, 240, 264, 288, 312, 336, 360, 384, 408, 432, 456) and (480) hours. The water absorption is calculated by the weight difference. The percentage weight gain of the samples is measured at different time intervals by using the equation (2.32).



Figure (3-15): The water absorption test.

3.8 The Finite Element Analysis (FEA)

The Finite element analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called finite element method (FEM). Engineers use it to reduce the number of physical prototypes and experiments and optimize components in their design phase to develop better products, faster. It is necessary to use mathematics to comprehensively understand and quantify any physical phenomena such as structural or fluid behavior, thermal transport, wave propagation, the growth of biological cells, etc. Most of these processes are described using partial differential equations (PDEs). However, for a computer to solve these PDEs, numerical techniques have been developed over the last few decades and one of the prominent ones, today, is the finite element analysis. Differential equations can not only describe processes of nature but also physical phenomena encountered in engineering mechanics. These partial differential equations (PDEs) are complicated equations that need to be solved in order to compute relevant quantities of a structure (like stresses (σ), strains (ϵ), etc.) in order to estimate a certain behavior of the investigated component under a given load. It is important to know that FEA only gives an approximate solution of the problem and is a numerical approach to get the real result of these partial differential equations. Simplified, FEA is a numerical method used for the prediction of how a part or assembly behaves under given conditions. It is used as the basis for modern simulation software and helps engineers to find weak spots, areas of tension, etc. in their designs. The results of a simulation based on the FEA method are usually depicted via a color scale that shows for example the pressure distribution over the object.


4.1 Introduction

This chapter firstly, studies the effect of experimental results of pure ER and ER with different ratios (0,5,10,15,20,30,40 and 50%) of PF and studies their mechanical and physical properties, was obtain the best ratio of 5%ER/95%PF. Secondly studies reinforced the 5%ER/95%PF by (1%) of MgO and ZrO nanoparticles which are used to prepare ER/PF/MgO and ER/PF/ZrO and then studying their mechanical and physical properties. The third step reinforced the 5%ER/95%PF by (1%) of GF, CF and KF fibers and studying fibers behavior under mechanical and physical properties. Finally, reinforced 5%ER/95%PF hybrid composite material by nanoparticles and fibers ER/PF/ZrO/GF, ER/PF/ZrO/CF, ER/PF/ZrO/KF, ER/PF/MgO/GF, ER/PF/MgO/CF and ER/PF/MgO/KF with studying the effect nanoparticles and fibers on mechanical and physical properties.

4.2 The Mechanical and Physical Properties of ER/PF blend with Different Mass Fractions of Addition

4.2.1 Tensile Test

From stress-strain curves in tensile test it can get the tensile strength, maximum force, tensile modulus and etc., for neat ER and ER/PF blend. The figure (4-1) shows the stress-strain curves of tensile test for ER which agreed with material data sheet provided by manufactured company and ER/PF composite with different mass fractions of addition from (0%) to (20%) of PF. The results values of tensile strength and other parameters of ER and ER/PF blend with various mass fractions of PF are listed in table (4-1). The results values of tensile strength and other parameters have most possibly high values at low mass fraction of ER/PF composite, specifically at (5%) fraction maximum

increment obviously appeared due to the strengthening of bonds and the filling of voids between ER and PF interpenetrating polymer network. Higher addition of 85%ER/15% PF and more led to saturation with ER and this decrease the mechanical and physical properties [69].



Figure (4-1): Stress-strain curves of tensile test for ER and ER/PF blend with (0-20%) of PF.

The fracture resistance values of composite materials increase at higher rates with an increase in the mass fraction of the 5% PF, therefore the fracture resistance values decrease when the mass fraction increases to 15% PF but the tensile resistance values at the fracture point of other samples remain low, this is due to the increased mass fraction of PF has made it difficult to penetrate into ER matrix when it contains mass fractions higher than (15%), which reduced the convergence between the surfaces of the matrix material ER and PF as well as the surfaces of molecules from each other sufficiently.

Symbol	Tensile Test									
of	F _m	R _m	FeH	FeL	ReH	ReL	Fp	Rp	Е	
Samples	(kN)	(MPa)	(kN)	(kN)	(MPa)	(MPa)	(kN)	(MPa)	(MPa)	
ER	0.198	25	0.203	0.195	25.5	24.5	0.172	21.67	19.2	
95%ER/ 5% PF	0.202	25.3	0.191	0.191	24	24	0.179	22.3	22.7	
90%ER/ 10%PF	0.188	23.67	0.183	0.181	23	23	0.147	18.67	13.77	
85%ER/ 15% PF	0.09	11.33	0.085	0.083	10.5	10.5	0.071	9	7.28	
80%ER/ 20%PF	0.03	1.2	0.03	0.02	1.67	1.6	0.011	1	1.1	
70%ER/ 30%PF	-	-	-	-	-	-	-	-	-	
60%ER/ 40%PF	-	-	-	-	-	-	-	-	-	
50%ER/ 50%PF	-	-	-	-	-	-	-	-	-	

 Table (4-1): Tensile test of ER/PF blend with different mass fractions of addition.

This made the process of having a liquid the matrix material of the PF surfaces is incomplete process leading reduce the bonding between the matrix material ER and the reinforcing material PF, which reduces the efficiency of the transfer of the load on the composite material and therefore it will be fracture with less stress and then the difficulty of penetration may weaken the adhesion forces as well as create many defects within the composite material and other defects is formed within the prepared layer itself will generate many stress concentrations that accelerate the process of sample failure and make the material behave as a brittle material [70].

4.2.2 Bending Test

Figure (4-2) shows the stress-strain curves in bending test for net ER and ER/FP composite with different mass fractions of addition from (0 - 15%) of PF, table (4-2) shows bending strength and other parameters of ER and ER/PF composite with various mass fractions of PF which agreed with material data sheet provided by manufactured company and for ER/FP composite with different mass fractions of addition from (5-15%). The results values of bending strength and other parameters have most possibly high values at low mass fraction of ER/PF composite, specifically at (10%.) fraction maximum increment obviously appeared, at higher addition of PF, bending strength of ER/PF composite decrease with increasing concentration of PF but the results values of bending strength at (5-10%) still higher than that of neat ER, and the rest of the mixing ratios were neglected because the parameters of them are very low as shown in the table (4-2).



Figure (4-2): Stress-strain curves of bending test for ER and ER/PF blend with (0-15%) of PF.

Symbol of Sample	U(MPa)	Maximum Stress (MPa)	Maximum Strain	E (MPa)
ER	0.186	0.186	32.63	0.008
95%ER/ 5% PF	0.224	0.224	28.12	0.01
90%ER/ 10%PF	0.3	0.3	36.94	0.012
85%ER/ 15% PF	0.1067	0.1067	37.34	0.007
80%ER/ 20%PF	-	-	-	-

 Table (4-2): Bending test of ER/PF blend with different mass fractions of addition.

The addition PF with various mass fractions ER increase bending strength and decreased at 85%ER/15% PF, this is due to the use of PF will increase the contact area between the components of the composite material prepared to penetrate within the distances and then increase the strength of bonding between them and increase the endurance of external stresses and also note the reduction of bending strength values with increased mass fraction PF this is due to the high viscosity acquired by the prepared sample when the addition of high mass fraction of PF to the ER matrix material in the liquid state, which caused the difficulty of penetration of the matrix material into the gaps of interfaces and pores within the composite material, which leads to saturation in filling the spaces in interfaces distances and reduced molecular bonding and weakness will lead to increased creation of air defects and gaps despite try to remove air gap and space, some of them have been retained when the composite material has hardened, which are considered centers of concentration of the stress and thus reduce the endurance of the composite material and external loads increase cracks and brittle fracture [68].

4.2.3 Impact Test

Figure (4-3) shows that the impact strength decreases with increasing of mass fraction of PF, the best result with blend, impact strength reduces from maximum increment this may be due reduce mobility of polymer chains [28].



Figure (4-3): Impact strength of ER/PF composite with various mass fractions of PF.

The impact test is an important mechanical dynamic test in which the material is subjected to a very fast kinetic load. The impact test on the samples by Charpy method at room temperature, the impact resistance of the composite material ER or ER/PF has been calculated by the energy required to obtain a fracture in the sample. the samples are divided into two parts, which suffer from a brittle fracture at the impact of the sample pendulum while other samples suffer to a ductile fracture, where the impact resistance value decreases with increasing add mass fraction more than 15% PF and the results are brittle fracture and the impact resistance is increased if the mass fraction ratio is low than 10% PF and the samples are of high strength fracture. The last value of the impact fracture strength of material decreases slightly to increase the ratio of PF

which leads to poor mixing with the ER which reduces the wettability and that the increase of interfacing between the ER and PF will lead to an increase in defects and decrease in the amount of energy required for the occurrence of the fracture, which is that the material ruptures when there are cracks in the matrix material and the boundary between the ER and PF. In general, the failure of the nonreinforced resin subjected to the impact test occurs by fraction the bonds or forces in the polymer by the growth of the initial cracks caused by the impact stresses. The polymer chains are represented by Van der Waals forces, which require little energy to overcome them, cracks extending perpendicular to the direction of the polymer chains destroy the chains during propagation, this requires more energy to overcome those forces responsible for linking synthetic units represented by covalent bonds [68].

4.2.4 Hardness Test

Addition PF with various mass fractions ER lead to increase the hardness at (5%) and decrease hardness when increase the addition as shown in figure (4-4), due to attributed to uniform dispersion of the PF in ER matrix [98]. A significant enhancement in hardness was observed for (5%). High strength of PF reinforcements may result in creating a network structure that improves the hardness of the composites [98]. When filler loading was increased beyond (5%) a decrease in hardness is observed and value drops down. We take the optimal result of mechanical properties 95%ER/5%PF to reinforced with nanoparticles and fibers. The hardness tests depend on the penetration resistance of the material at its outer surface. There are different methods that represent the hardness points, and the hardness value of the samples increase with increasing the mass fraction of the PF.



Figure (4-4): Shore D hardness of ER/PF blend with various mass fractions of PF.

The hardness value reach the highest value at (5%) than the pure ER and then decreased to the lowest value at (20%), and this is due to the high viscosity gained by the prepared samples when adding high ratios of PF to the ER in the liquid state, which caused the difficulty of penetration of the ER into the interfaces inside the composite materials and this led to creation of many gaps within the prepared material and despite the attempts made to get rid of the gaps, some of them were retained when the composite material was hardened, which is considered as centers of stress concentration, which resulted in low hardness values, since the hardness is characteristic of the surface of the material and due to the PF at the surface with the ER and sometimes those PF have high brittle at high ratio therefore, resistance to the force on them is small so the increase in hardness values are small with the increase of mass fraction of PF [98].

4.2.5 Thermal Conductivity Coefficient Test

Thermal conductivity behavior of ER/PF blend exhibited the maximum value at 95% ER/5% PF and this is value decrease when increase the mass fraction of the PF and this due to the weak bound between the chains of ER and PF which decrease the thermal conductivity of blend as shown in figure (4-5) and table (4-3).



Figure (4-5): Thermal conductivity of ER/PF blend with various mass fractions of PF.

Polymer materials show a weak thermal conductivity. Thermal conductivities of insulating polymer materials are usually (1-3) orders lower than those of ceramics and metals. Due to the chain-like structure of polymers, the heat capacity consists of the contribution of two mechanisms: (a) lattice vibrations and (b) characteristic vibrations, which originate from internal motions of the repeating unit. The lattice vibrations are acoustic vibrations, which give the main contribution to the thermal conductivity at low temperatures. Temperature, pressure, density of the polymer, orientation of

chain segments, crystal structure, the degree of crystallinity and many other factors may affect the thermal conductivity of polymers [63].

Table (4-3): Thermal conductivity coefficient of ER/PF blend with
various mass fractions of PF.

Ta (k)	Tb (k)	Tc (k)	r (m)	ds (m)	d A,B,C (m)	l (Amp)	V (Volt)	h (W/m².k)	k (W/m.K)	Sample
314	341	351	0.02	0.0031	0.013	1.72	6.1	4.04660273	0.3468525	100%ER
321	340	354	0.02	0.003	0.013	1.72	6.1	4.0167832	0.4835267	95%ER/5%PF
317	344	353	0.02	0.00312	0.013	1.72	6.1	4.01164049	0.3494541	90%ER/10%PF
316	349	356	0.02	0.00322	0.013	1.72	6.1	3.97906185	0.2920683	85%ER/15%PF
315	350	357	0.02	0.00294	0.013	1.72	6.1	3.99430187	0.2508568	80%ER/20%PF

4.2.6 Dielectric Test

The variations of dielectric constant at frequency range up to $(1 \times 10^{6} \text{ Hz})$ at room temperature for the ER/PF composite with (0, 5, 10, 15 and 20%) of PF are shown in figure (4-6).



Figure (4-6): Dielectric constant of ER/PF composite with various mass fractions of PF as a function of frequency.

The high dielectric constant value of the ER/PF blend at low frequencies of imposed voltage is due to free dipolar functional sets of ER chains which orientate themselves with the imposed voltage, this preform to high dielectric constant, while at intermediate and higher frequencies of imposed voltage (duration of imposed voltage is very short) several of non-free dipolar functional sets will not respond to the imposed voltage which lead to decrease dielectric constant [111]. The dielectric constant of ER/PF blend illustrated almost flat region till to $(1 \times 10^6 \text{ Hz})$. The dielectric constant of EP/ PF composite with (0, 5, 10, 15 and 20%) of PF increase in clear manner comparing with the dielectric constant of PF which has higher dielectric constant than ER and the same behavior with dielectric loss as shown the figure (4-7).



Figure (4-7): Dielectric loss of ER/PF composite with various mass fractions of PF as a function of frequency.

The A.C. electrical conductivity adopted on the number of charge carriers and frequency of the imposed electric field on the composites. The rising of mass fraction of ER/PF composite improved the sources of charge carriers. The charge carriers can pass though the overlapping interaction regions of the ER matrix of EP/PF composites. The overlapping of interaction region (percolation influence) depends on; filler content, dispersion and the filler size. This behavior refers to balancing in the mechanisms that effect on the A.C. electrical conductivity [111] as shown in figure (4-8).



Figure (4-8): A.C. electrical conductivity of ER/PF composite with various mass fractions of PF as a function of frequency.

4.2.7 The Water Absorption Test

The water absorption test of ER/PF blend were based on the per ASTM 570 by immersion in distilled water at room temperature. The samples were taken out periodically (0,5,10,15 and 20%) of PF and after wiping out the water from the surface of the sample weighted immediately using a precise balance machine

to find out the content of water absorbed. The specimens were weighed regularly at (24, 48, 72, 96, 120, 264, 360, 456 and 504 hours). The water absorption is calculated by the weight difference. The percentage weight gain of the sample is measured at different time intervals by using the equation (2-32). As shown in figure (4-9) we notice the high value of absorption when increase the ratio of PF with ER and the water absorption process is sharp at the beginning and levelled off for some length of time where it approaches to equilibrium. Generally, the rate of water absorption is greatly affected by the blend's density and voids content which cause more water absorption rate as compared to 5% PF content [141].



Figure (4-9): The water absorption of ER/PF composite with various mass fractions of PF as a function of time.

4.3 The Mechanical and Physical Properties of Reinforced Composite Material (ER/PF with Nanoparticles)

4.3.1 Tensile Test

We obtained the optimum results of all mechanical and physical properties and chosen the ratio of 95%ER5%PF. Figure (4-10) shows the stress-strain curves of tensile test for 1% MgO and 1% ZrO nanoparticles with 95%ER5%PF, we obtained the maximum stress with ZrO nanoparticles due to the high strength of ZrO nanoparticles with composite material and maximum strain with MgO and ZrO nanoparticles because of ductility properties of MgO and ZrO nanoparticles than 95%ER/5%PF.



Figure (4-10): Stress-strain curves of tensile test for MgO and ZrO nanoparticles with 95%ER/5%PF.

The tensile strength of the samples was increased by adding mass fraction of the nanoparticles and up to twice or more what they were before the addition of nanoparticles and this is due to the contribution nanoparticles in bearing the forces on the hybrid composite materials and to suit with their nature and mass fraction since nanoparticles have very high tensile strength compared to hybrid composites as well as their uniform random distribution within the polymer material and the ease of penetration of the matrix material between these nanoparticles, which creates perfect interfaces between the matrix material and reinforcement materials and also the compatibility between the matrix material and the nanoparticle which led to an increase in tensile strength values [72].

4.3.2 Bending Test

Figure (4-11) shows the stress-strain curves of bending test for MgO and ZrO nanoparticles with 95%ER5%PF. We obtained the maximum and sharp stress with ZrO and MgO nanoparticles than 95%ER5%PF due to the properties of materials are supposed to be uniform through the distribution of force although the usual linear pressure on one surface varies to the maximum tension on other surface when the surface midpoint of the sample cause bending this is the moment of bending [70].



Figure (4-11): Stress-strain curves of bending test for MgO and ZrO nanoparticles with 95%ER/5%PF.

The effect of the filling of nanoparticles on the bending strength value and shear stress value that the use of particles in small sizes nanoscale and (1%) led to increase the bending strength value and shear stress value compared with the nonreinforced samples values, the properties of nanoparticles have high bending strength value and this is due to use nanoparticles will facilitate the wettability of the matrix material of the reinforcing materials, which increases the contact area between the components of the prepared composite material and reduces the creation of defects and airspace and thus increase the bonding strength between them increase the endurance to external stresses [68].

4.3.3 Impact Test

MgO and ZrO nanoparticles were found to increase the impact strength of 95%ER/5% PF and the best result was ER/PF/MgO with big difference than 95%ER/5%PF as shown in figure (4-12).



Figure (4-12): Impact strength of MgO and ZrO nanoparticles with 95%ER/5%PF.

The increase in impact strength of polymer blend with the addition in the nanoparticles can be attributed to uniform dispersion of the nanoparticles in polymer blend matrix and this result in creating a network structure that improves the impact of the composites more than polymer blend [96].

The effect of the reinforced nanoparticles on the impact resistance values of the samples increases with the addition of nanoparticles compared to the nonreinforced composite material, for the ease of penetration of nanoparticles and interfaces into network ER/PF blend, which increases the wettability ER/PF blend to the reinforcement materials and it will increase the contact area and thus increase the bonding strength between the components of the prepared ER/PF blend while minimizing the defects which act as centers of stress concentration and increase the energy required for the fracture and thus increase the impact resistance values [72]. Nanoparticles act as prevents to the progress of fracture and this ability depends on the strength of the interconnection of the interface between the reinforcing material and ER/PF blend so that the fracture moves through the interface around the nanoparticles in case of failure of those particles. In addition, this relationship depends on the percentage of the fracture of particle size, shape, size and distribution system within ER/PF blend [96].

4.3.4 Hardness Test

As shown in the figure (4-13) the hardness increase with adding nanoparticles with the 95%ER/5%PF which was their hardness value the minimum, the maximum hardness values were MgO and ZrO nanoparticles with matrix which reduce plastic deformation into blend matrix where interfacial space among nanoparticles and blend consider a strong region which is stronger than ER and when enhancement with nanoparticles MgO and ZrO [98]. The concept of hardness is a measure of the plastic deformation that the material can suffer under external stress and thus the addition of nanoparticles has increased the hardness of the material due to its increased resistance to plastic deformation.



Figure (4-13): Shore D hardness of MgO and ZrO nanoparticles with 95%ER/5%PF.

The addition of nanoparticles to the composite material has led to reduction of elasticity and an increase in the surface resistance to penetration, and that these nanoparticles have strength properties and when introduced into the laminates to be reinforced will increase the hardness value. The effect of nanoparticle filling on hardness value has been found that the hardness value increase with the addition of nanoparticles because it facilitates the process of penetration smoothly into the ER/PF blend and into the interfaces of the polymer material network and into the interfaces pores formed during the preparation of the composite material all this helped to increase the contact area between the components of the composite material and then increase the bonding between them, which gave more positive values when hardness testing [98].

4.3.5 Thermal Conductivity coefficient Test

We take the best result from thermal conductivity test of ER/PF blend and it was 95% ER/5% PF and reinforced with (1%) MgO and ZrO nanoparticles as shown in the figure (4-14). The thermal conductivity properties of nanocomposite materials depend on the type, size and mass fraction of the nanoparticles and notice ER/PF/MgO and ER/PF/ZrO have lower thermal conductivity values than 95% ER/5% PF due to MgO and ZrO nanoparticles have very weak thermal conductivity. The reason for this behavior is that the MgO and ZrO nanoparticles act as barriers to the transfer of heat because MgO and ZrO nanoparticles are poorly conducting heat and impede the vibratory motion of the resin structure, thus reduces the thermal conductivity [32].



Figure (4-14): Thermal conductivity of MgO and ZrO nanoparticles with 95%ER/5%PF.

4.3.6 Dielectric Test

The variations of dielectric constant at frequency up to $(1 \times 10^6 \text{ Hz})$ for the ER/PF blend at the best result was 95%ER/5%PF and with various nanoparticles MgO and ZrO as shown in figure (4-15) at room temperature, we obtain higher

value of dielectric constant at 95%ER/5%PF than with MgO and ZrO nanoparticles and this due to the permittivity indicate the ability of a material to polarize in response to an imposed field [44].



Figure (4-15): Dielectric constant of MgO and ZrO nanoparticles with 95%ER/5%PF.

We notice from the dielectric loss as shown in the figure (4-16) and A.C. electrical conductivity as shown in the figure (4-17), the reinforced by MgO and ZrO nanoparticles lead to improve the dielectric properties due to nanocomposites have a large concentration of ER/PF/nanoparticles interfaces because of large surface zone of nanoparticles, therefore the most dominated polarizations kind are interfacial polarizations. This behavior refers to balancing in the mechanisms that effect on the A.C. electrical conductivity.



Figure (4-16): Dielectric loss of MgO and ZrO nanoparticles with 95%ER/5%PF.



Figure (4-17): A.C. electrical conductivity of MgO and ZrO nanoparticles with 95%ER/5%PF.

4.3.7 The Water Absorption Test

Water absorption test for the 95%ER/5%PF and with various nanoparticles MgO and ZrO are shown in figure (4-18), It can notice that ER/PF/MgO has a higher value of absorption more water and dimensional changes. The ability of water absorption increased when enhanced with nanoparticles MgO and ZrO due to the higher surface area of nanoparticles reinforces larger volume of resin matrix and stress can be moved to nanoparticles more competently owing to high interfacial area between resin and filler and this reduce water immersion [58].



Figure (4-18): The water absorption of MgO and ZrO nanoparticles with 95%ER/5%PF.

4.4 The Mechanical and Physical Properties of Reinforcement Composite Material (ER/PF with Fibers)

4.4.1 Tensile Test

We obtained the optimum results of all mechanical and physical properties and chose the ratio of 95%ER5%PF. Figure (4-19) shows the stress-strain curves of tensile test of (1%) from GF, CF and KF fibers with 95%ER/5%PF, we obtained the maximum stress with CF fibers due to the high strength of CF fibers with composite materials and maximum strain with KF fibers because of ductility properties of KF fibers than 95%ER/5%PF.



Figure (4-19): Stress-strain curves of tensile test for GF, CF and KF fibers with 95% ER/5%PF.

The tensile strength of the composite materials varies with the type of fibers is due to the characteristics of the fibers characterized by high tensile strength as well as high flexibility compared to each type of fibers: KF, GF and CF because of the properties of these fibers (high strength and impact), in addition to the relatively rough nature of the surface because it contains fine fibers, which leads to a mechanical link between the fibers and the matrix material, which in turn leads to the need for additional energy to dissolve fibers from the matrix material, especially since the fibers bear the biggest part of the external stress on the composite materials and endurance of fibers are proportional to the mass fraction and the nature of the fibers used in the reinforced materials. The addition of mass fraction of fibers increased wettability within the matrix material, which makes them as centers of concentration stresses and then reduce defects and cracks and thus will increase the bond between the matrix material and reinforcement materials and strengthen the composite materials [69].

4.4.2 Bending Test

Figure (4-20) shows the stress-strain curves of bending test for GF, CF and KF fibers with 95%ER/5%PF. We obtained the maximum and sharp stress with CF fibers due to that the properties of materials are supposed to be uniform through the distribution of force although the usual linear pressure on one surface varies to the maximum tension on other surface when the surface midpoint of the sample cause bending and this is called the moment of bending [70].



Figure (4-20): Stress-strain curves of bending test for GF, CF and KF fibers with 95%ER/5%PF.

It was found that the bending strength value and the value of the greatest shear stress increase when reinforcing the matrix material by KF and CF and GF fibers, because of these fibers have resistance to compression and shear stress in addition to the nature of their relatively rough surface, because they contain fine fibers, which leads to mechanical link between fibers and matrix material, which in turn leads to the need for additional energy to fracture fibers from the matrix material, especially that the fibers bear the biggest parts of the external stress on the composite material and that the endurance of these fibers is proportional to the mass fraction and nature of fibers, the addition of mass fraction of fibers increased the wettability of the matrix material, making it as centers of stress concentration, then defects and cracks will be reduced, thus increasing the bonding between the matrix material and the reinforcing materials and strengthening the sample. CF and GF fibers have isotropic properties and are strong against shear stress and compression. KF fibers have anisotropic properties and are weak towards shear stress and compression stress [70].

4.4.3 Impact Test

Fibers were found to increase the impact strength of 95%ER/5%PF and the maximum value of impact strength was found at ER/PF/KF as shown in figure (4-21). The increases in impact strength of polymer blend with the addition of the fibers can be attributed to uniform dispersion of the fibers in polymer blend matrix and this result would be creating a network structure that improves the impact strength of the composites [28]. In addition to the relatively rough nature of the surface because it contains fine fibers filaments, which leads to mechanical linking between the fibers and the ER/PF composite, which in turn leads to the request for additional energy to rupture fibers from the ER/PF composite.



Figure (4-21): Impact strength of GF, CF and KF fibers with 95%ER/5%PF.

The composite materials reinforced by KF fibers have the best impact strength value due to nature the fiber and the direction of the fibers is parallel to the force direction which leads to bearing high stresses and thus to absorb most of the energy, while the impact of the laminated system in the reinforcement of fibers on impact strength values of the samples the lamination reinforced system affects increasing the impact strength values of the fibers-reinforced samples [68].

4.4.4 Hardness Test

As shown in the figure (4-22) the hardness increases with adding the fibres with 95%ER/5%PF blend which was their value the minimum. The maximum hardness value was ER/PF/GF with matrix which reduce plastic deformation into blend matrix where interfacial space among fibres and blend consider a hard region which is harder than ER/PF composite [98].



Figure (4-22): Shore D hardness of GF, CF and KF fibers with 95%ER/5%PF.

It was found that the positive effect of reinforcing 95%ER5%PF by fibers (KF, CF, and GF), has a role in the property of hardness. Highest hardness value was 95%ER5%PF with GF, this is due to the nature of GF fibers, which has a higher hardness than that of KF fibers because GF fibers are prepared from ceramic materials, while KF fibers prepared from polymeric materials.

4.4.5 Thermal Conductivity Coefficient Test

We take the best result from thermal conductivity test of ER/PF blend and it was 95%ER/5%PF and reinforced with different fibers (KF, CF, and GF) as shown in figure (4-23) it can notice that all the fibers composites have a high values than 95%ER/5%PF. Thermal conductivity of composite materials depends on the orientation, thickness, mass fracture, type, and number lamination of with the fibers. In general, the thermal conductivity of the resins increases after reinforcing the fibers, and this increase is expected due to the ability of the fibers as a whole to thermal conductivity compared to the matrix material. The increase in thermal conductivity is due to that CF fibers are a better conductor of heat than that 95%ER/5%PF and this increase in thermal conductivity is expected due to the ability of the fibers to conduct heat compared to the resin. The composites consisting of fibers have a thermal conductivity resulting from increased condensation and agglutination between the layers of fibers and absorb thermal energy that helps the structural vibration in the internal structure of the composite molecules [63].



Figure (4-23): Thermal conductivity of GF, CF and KF fibers with 95%ER/5%PF.

4.4.6 Dielectric Test

The variations of dielectric constant at frequency up to $(1 \times 10^6 \text{ Hz})$ at room temperature for the ER/PF blend at the best result 95%ER/5%PF with various fibers GF, CF and KF are shown in the figure (4-24) we obtain higher value of dielectric constant at ER/PF/CF than 95%ER/5%PF and this is due to that the permittivity indicates the ability of a material to be polarized in response to an imposed field [102]. It is the ratio of the permittivity of the dielectric to the permittivity of a vacuum [112] and for the same previous reasons, as shown in the figure (4-25) the dielectric loss of 95%ER/5%PF reinforced by GF, CF and KF fibers. Physically it means the greater the polarization developed by a material in an imposed field of given strength, the greater the dielectric constant will be [112].



Figure (4-24): Dielectric constant of GF, CF and KF fibers with 95%ER/5%PF.



Figure (4-25): Dielectric loss of GF, CF and KF fibers with 95%ER/5%PF.

Alternative current conductivity of 95%ER/5%PF and with various fibers GF, CF and KF is shown in the figure (4-26). We notice that the ER/PF/CF has

high value than nonreinforced of 95%ER/5%PF blend. ER/PF/KF and ER/PF/GF composites slightly was improved due to they contain polymeric fibers and has the same dielectric properties and the permittivity indicate the ability of a material to polarize in response to an imposed field [111].



Figure (4-26): A.C. electrical conductivity of GF, CF and KF fibers with 95%ER/5%PF.

4.4.7 The Water Absorption Test

Water absorption test of the immersed samples in distilled water was carried out at room temperature. From the figure (4-27), It can notice that all samples (reinforced and non-reinforced) are increased in weight in immersion start in distilled water. The experimental results revealed that ER, PF and KF with high value of absorb more water which show a low in density and contains a high content of the voids [121] as shown in figure (4-27).



Figure (4-27): The water absorption of GF, CF and KF fibers with 95%ER/5%PF.

4.5 The Mechanical and Physical Properties of Reinforcement Composite Material (ER/PF with Nanoparticles and Fibers)

4.5.1 Tensile Test

Figures (4-28) and (4-29) show the stress-strain curves of tensile test for 95%ER/5%PF was reinforced with (1%) GF, CF and KF fibers and nanoparticles (1% nano-MgO and 1% nano-ZrO), we obtained at both figures the maximum stress with CF fibers clearly improved properties of the compound material because they occupy more space within the resin and fibers allowing better distribution of the load [60], and maximum strain with KF fibers which increase with nanoparticles filler because of the small volume of fillings leading to a large increase in the interstitial area, which creates a large part of polymer interaction with nanoparticles in the structure of polymeric particles, which plays an important role in reinforcement, strength of polymers structure and ductility properties of KF fibers [60].



Figure (4-28): Stress-strain curves of tensile test for nano-MgO and GF, CF and KF fibers with 95%ER/5%PF.



Figure (4-29): Stress-strain curves of tensile test for nano-ZrO and GF, CF and KF fibers with 95%ER/5%PF.

From table (4-4) we obtain the tensile strength (Rm), Young's modulus (E) and other parameters of composite materials, and we notice that the best results

of tensile strength are found in composite materials reinforced by CF fibers with ZrO and MgO nanoparticles due to CF fibers characteristics of reinforcing composite materials and occupy all the voids and strengthening the interconnections to make it bear the tensile strength and mitigation as well as for the Young's module [72].

Composite	Tensile Test									
Material	Fm(kN)	R _m (MPa)	FeH(kN)	FeL(kN)	ReH(MPa)	ReL(MPa)	Fp(kN)	Rp(MPa)	E(MPa)	
ER/PF/MgO/CF	13.39	255	12.78	12.77	243	243	-	-	31.03	
ER/PF/MgO/GF	3.290	63	3.238	3.236	62	62	2.134	41	9.5	
ER/PF/MgO/KF	5.315	101	3.478	2.910	66	55	2.716	52	14.2	
ER/PF/MgO	0.946	18	-		-	-	0.918	17	5.67	
ER/PF/ZrO/CF	5.885	112	-	-	-	-	5.870	112	22.7	
ER/PF/ZrO/GF	4.368	83	4.304	1.806	82	34	3.028	58	14	
ER/PF/ZrO/KF	6.545	125	-	-	-	-	3.320	63	13.95	
ER/PF/ZrO	1.488	28	-	-	-	-	1.088	21	6.2	
ER/PF/CF	13.71	261	-	-	-	-	-	-	31.53	
ER/PF/GF	4.870	93	_	-	-	-	3.792	72	13.83	
ER/PF/KF	5.510	105	3.328	2.886	63	55	2.886	55	13.9	

Table (4-4): The parameters of tensile test for composite materials.

It was found that the relationship between the mass fraction of the reinforced nanoparticles and the tensile strength of the samples is that the tensile strength values are increased by adding the fractional mass of nanoparticles and these values are twice as high or more as before the nanoparticles were added. The nanoparticles have very high tensile strength compared to GF, KF and CF fibers, as well as their regular random distribution within the polymer material and the ease of penetration of the matrix material between the nanoparticles. These nanoparticles and fibers within the gaps are contained within the layers of fibers woven without causing any defects within the fibers network, and this increases the ability of the medium of the mixture of ER and PF to moisturize, especially when the medium is a liquid material before the hardening process composite materials. Increased wetness between the medium and the reinforcing

material creates perfect interfaces between the matrix material and the reinforcing material, as well as the compatibility between the matrix material and the nanoparticles on the one hand and between the nanoparticles and the fibers on the other hand, resulting in an increase in the tensile resistance values. It was also observed that the tensile strength of the samples varies with the type of fibers used and this is due to the characteristics of the fibers characterized by high tensile strength and high flexibility compared to each type of fibers: KF, GF and CF especially that the fibers bear the biggest part of the external stress on the composite material and that the endurance of these fibers is proportional to the mass fraction and the nature of the fibers used in the reinforcement.

4.5.2 Bending Test

Figures (4-30) and (4-31) show that the stress-strain curves of bending test for 95%ER/5%PF that enhanced with GF, CF and KF fibers in addition nanoparticles MgO and ZrO it can notice maximum and sharp curve of ER/PF/MgO/CF due to the high stress properties of MgO and ZrO nanoparticles with CF fibers and notice all values of reinforced composite materials with fibers increase when adding the nanoparticles, they have small size of filling leading to a huge rise in the interstitial area which plays an important role in reinforcement bending strength [8]. Wide maximum curve of strain was obtained of composite reinforced with KF fibers and both nanoparticles due to ductile properties of KF fibers and strength of nanoparticles. In the table (4-5), ER/PF/MgO/CF has the maximum ultimate strength and yield strength due reduce mobility of polymer chains because of strength fibers and hard nanofiller can be the reason for high bending strength [70]. Higher surface area of nanoparticles reinforces larger volume of resin matrix and stress can be moved to nanoparticles more competently owing to high interfacial area between resin and filler [70].



Figure (4-30): Stress-strain curves of bending test for nano-MgO and GF, CF and KF fibers with 95%ER/5%PF.



Figure (4-31): Stress-strain curves of bending test for nano-ZrO and GF, CF and KF fibers with 95%ER/5%PF.
	Bending Test						
Composite	Ultimate	Yield	Maximum	Maximum			
Material	Strength (KN)	Strength	Stress	Strain			
	Suchgui (KN)	(KN)	(MPa)	Suam			
ER/PF/MgO/CF	0.24	0.2	2.38	17.524			
ER/PF/MgO/GF	0.12	0.08	1.22	35.946			
ER/PF/MgO/KF	0.14	0.07	1.36	51.044			
ER/PF/MgO	0.06	0.025	0.58	35.7			
ER/PF/ZrO/CF	0.05	0.02	0.54	53.782			
ER/PF/ZrO/GF	0.08	0.025	0.840	19.468			
ER/PF/ZrO/KF	0.09	0.025	0.860	39.496			
ER/PF/ZrO	0.08	0.024	0.820	33.278			
ER/PF/CF	0.20	0.15	2.020	20.708			
ER/PF/GF	0.12	0.09	1.180	39.946			
ER/PF/KF	0.07	0.05	0.700	24.436			

Table (4-5): The parameters of bending test for composite materials.

It was found that bending strength value and the maximum shear stress value increase when add nanoparticles to the matrix material reinforced by KF, CF and GF fibers because these nanoparticles have resistance to compression and shear stress compared to KF, CF and GF fibers, the addition of mass fraction of nanoparticles with fibers increased wettability within the matrix material, which makes it as centers of stress concentration, then the defects and cracks will be reduced, thus increasing the bonding between the matrix material and reinforcement and strengthen the sample. CF and GF fibers have Isotropic properties and are strength against shear stress and compression, KF fibers have anisotropic properties and are weak to shear stress and compression stress [68].

4.5.3 Impact Test

Impact strength was increasing when 95%ER/5%PF blend reinforcing by MgO and ZrO nanoparticles with GF, CF and KF fibers and the maximum value

was ER/PF/MgO/KF and ER/PF/ ZrO /KF as shown in figures (4-32) and (4-33).



Figure (4-32): Impact strength of GF, CF and KF fibers and nano-MgO

with 95%ER/5%PF.



Figure (4-33): Impact strength of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

We notice from the table (4-6) high of value impact strength for composite material reinforced by KF fibers and ER/PF/MgO/KF due to the ductility properties of the KF fibers on polyamide, which made them distributed with polymer chains and are associated with strong bonds with the matrix, which made them resist strong shocks in the impact test [28].

Composite Material	Impact (J)
ER/PF/ZrO	0.3
ER/PF/MgO	0.25
ER/PF/GF	1.25
ER/PF/CF	0.7
ER/PF/KF	2.15
ER/PF/ZrO/GF	1.25
ER/PF/ZrO/CF	1.4
ER/PF/ZrO/KF	1.6
ER/PF/MgO/GF	0.95
ER/PF/MgO/CF	1.4
ER/PF/MgO/KF	1.75

 Table (4-6): Impact strength of composite materials.

The particle and fibers reinforced composite material had higher fracture energies than the nonreinforced composite material as reinforced with KF fibers are higher than those of nanoparticle-reinforced with GF or CF fibers, this may be due to the nature of KF and CF fibers because of its high impact resistance and high strength compared to samples reinforced by nanoparticles or GF fibers, which has the character of brittle and easily fracture into small pieces due to when an external force applies on nonreinforced material, it directly affects the material without any support from particles or fibers. The distance between the particles is large, the polymer absorbs this energy and vanish, but in the case of increasing the mass fraction of the nanoparticles the distance between the grain small grain [28].

4.5.4 Hardness Test

In figures (4-34) and (4-35) and table (4-7) when enhancement by various GF, CF, KF fibres and nanoparticles MgO and ZrO with 95%ER/5%PF.



Figure (4-34): Shore D hardness of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-35): Shore D hardness of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

Composite Material	Hardness
ER/PF/ZrO	76.2
ER/PF/MgO	77.4
ER/PF/GF	86.2
ER/PF/CF	84.5
ER/PF/KF	75
ER/PF/ZrO/GF	79
ER/PF/ZrO/CF	78
ER/PF/ZrO/KF	73.4
ER/PF/MgO/GF	80.8
ER/PF/MgO/CF	80
ER/PF/MgO/KF	78.2

Table (4-7): Hardness	of composite materials.
-----------------------	-------------------------

we obtain the rise of hardness value especially with GF fibres as shown due to the optimum concentration of nanoparticles which distribute into chain polymer and that leads to solidness on the materials [98]. The addition of MgO and ZrO nanoparticles has increased the hardness of the material due to its increased resistance to plastic deformation. The addition of nanoparticles to the composite material has led to reduction of elasticity and an increase in the surface resistance to penetration, and that these nanoparticles have strength properties and when introduced into the laminates to be reinforced will increase the hardness value [98]. Confirms the positive effect of reinforcing these fibers, the type of fibers (KF, CF, and GF), has a role in the property of hardness and this is due to the nature of GF fibers, which has a higher hardness than that of KF fibers because GF fibers are prepared from ceramic materials, while KF fibers prepared from polymeric materials. It has been found that ER/PF/GF has an influential role in hardness values as samples reinforced with GF fibers gave higher hardness values giving more positive results in the reinforcement process and that the laminated system in fibers reinforcement increases the hardness values of the samples [98].

4.5.5 Thermal Conductivity Coefficient Test

When enhanced the 95%ER/5%PF by various fibers and nanoparticles MgO and ZrO the result as shown in the figure (4-36) and (4-37). We obtain high values of thermal conductivity compared with 95%ER/5%PF and ER/PF/nanoparticles, that due to some parameters could be affecting the thermal conductivity such as filler size, concentration, geometry, dispersion, crystal structure, orientation, and interface between the polymer matrix and filler affect [118]. In general, the thermal conductivity of the resins increases after reinforcing the fibers, and this increase is expected due to the ability of the fibers as a whole to thermal conductivity compared to the matrix material [118].

The increase in thermal conductivity in ER/PF/MgO/CF and ER/PF/ZrO/CF are a better conductor of heat than ER/PF/MgO/GF, ER/PF/MgO/KF, ER/PF/ZrO/GF and ER/PF/ZrO/KF, this increase in conductivity is expected due to the ability of the fibers to conduct heat compared to the ZrO, MgO nanoparticles and ER/PF. The composites consisting of fibers have a thermal conductivity resulting from increased condensation and agglutination between the layers of fibers and absorb thermal energy that helps the structural vibration in the internal structure of the composite molecules [32].



Figure (4-36): Thermal conductivity of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-37): Thermal conductivity of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

4.5.6 Dielectric Test

When enhanced by various fibers and MgO and ZrO nanoparticles with 95%ER/5%PF as shown in the figure (4-38) and (4-39), we notice the nanoparticles and fibers improve the dielectric constant properties especially with ER/PF/Mg/CF and ER/PF/Zr/CF, this is due to nanocomposites have a large concentration and enhanced with fibers of ER/PF/nanoparticles and fibers have interfaces because of large surface area of nanoparticles and cross linked chain of fibers with polymers therefore the most dominated polarizations kind are interfacial polarizations [44].



Figure (4-38): Dielectric constant of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-39): Dielectric constant of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

Dielectric loss of 95%ER/5%PF which enhanced by various fibers and MgO and ZrO nanoparticles as shown in the figure (4-40) and (4-41), it was notice that dielectric loss properties improved when reinforced 95%ER/5%PF by MgO and ZrO nanoparticles and GF, CF and KF especially with ER/PF/MgO/CF and ER/PF/ZrO/CF, this is due to they have a large concentration and enhanced with fibers of ER/PF/nanoparticles and fibers have interfaces because of high surface area of nanoparticles and cross linked chain of fibers with polymers therefore the most dominated polarizations kind are interfacial polarizations [44], and all of those reasons the reinforced by nanoparticles (MgO and ZrO) and fibers (CF) made the A.C. electrical conductivity of 95%ER/5%PF improve and have large values as shown in the figure (4-42) and (4-43).



Figure (4-40): Dielectric loss of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-41): Dielectric loss of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.



Figure (4-42): A.C. electrical conductivity of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-43): A.C. electrical conductivity of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

4.5.7 The Water Absorption Test

Absorption test of the immersed samples in distilled water was carried out at room temperature. When we see the figures (4-44) and (4-45), it can notice that all samples (reinforced and non-reinforced samples) are increased in weight in immersion start in distilled water.



Figure (4-44): The water absorption of GF, CF and KF fibers and nano-MgO with 95%ER/5%PF.



Figure (4-45): The water absorption of GF, CF and KF fibers and nano-ZrO with 95%ER/5%PF.

It can notice that the water absorption and thickness swelling test, the ER/PF/MgO/CF and ER/PF/ZrO/CF have lower values of water absorption test and all dimensions of the samples are changed as shown in figure (4-44) and (4-45), due to the higher surface area of nanoparticles reinforces larger volume of resin matrix and stress can be moved to nanoparticles more competently owing to high interfacial area between resin and filler and the fibers nature, all these reduce water immersion [122].

4.6 Composite Materials Applications

4.6.1 Plastic Pipes

PVC is used to make plastic tubes, which reduces the use of iron and steel in the manufacture of these tubes. Accordingly, the plastic pipes are made of normal PVC, and the materials include polyvinyl chloride and some additives that give some properties and high strength pressures. Sewer pipes are designed to remove wastewater from plumbing inside the home and the street, and the use of PVC products is justified by the long service life of the sewer pipelines that will allow the system to operate up to (50 years), as the tensile strength reaches (50 MPa), and will also bear at a specific depth in the soil, it is able to work under pressure from (6 to 16 bar), the use of PVC pipes for wastewater has the following advantages:

- A variety of sizes and shapes of pipes and fittings will allow the sewer system to be assembled of any complexity.

- The soft inner walls do not allow pipes to settle, which prevents clogging in the small diameter.

- Small product weight and ease of cutting means fast and easy assembly and dismantling without additional tools.

- Inactivity of chemicals and corrosive effects.

- Reasonable price for pipeline items.

- Operating temperature range from (-10 to +65 degrees). At (-18 degrees), the polyvinyl chloride becomes brittle. The material is softening resistant when briefly heated to (+ 90 degrees).

- Plastic pipe elements are produced according to GOST 51613-2000. The dimensions of PVC pipes are determined by factors such as length, outer diameter, inner diameter and wall thickness:

A variety of sizes and shapes of pipes and fittings such as diameter and wall thickness of various pipes as shown in the table (4-8).

Dimeter, mm	Wall Thickness, mm
11-29	0.5-1.5
90	2.2–6.6
110	2.7-8.6
160	4.0–9.5
225	5.5–13.4
315	7.7–18.7
400	9.8–23.7
500	12.3–23.9

Table (4-8): Diameter and wall thickness of various pipes.

Main features:

- Affordable cost
- Cathodic protection is not required.
- Low thermal conductivity.
- Reliable protection against the spread of viruses and bacteria.

- Durability.
- Resistant to chemical effects and corrosion.
- Light weight.

Plastic pipes are equipped to last more than (50 years). Do not assume the need for continuous maintenance, products can have a variety of sizes as shown in the figure (46), if we are talking about a good diameter, it may be designed to increase the load, therefore, these pipes are installed to serve buildings from social facilities, homes and apartment buildings. For example, a diameter of (200 mm) is suitable for a hospital, hotel, or sauna. And if the diameter is more than (300 mm), then this tube will be suitable for the operation of industrial plants. The internal pressure depends on the thickness of the walls and the structure of pipes, the maximum value can reach (16 bars), while the minimum pressure is (6 bars). The temperature limit is (65 degrees) Celsius, and all the properties of the different plastic pipes compare with composite materials values as shown in the table (4-9) and (4-10).



Figures (4-46): Various pipes.

Properties	Alloy Steel		PVC Pipes		ER/PF/ZrO	ER/PF/MgO
Density (g/cm ³)	8.27			1.38	1.25	1.23
Tensile Strength (MPa)	42	20		52	28	18
Tensile Modulus (MPa)	20)0	3	9.0 - 3.3	6.2	5.67
Max. Strain to Failure (%)	4-	5.6		3-17	9.1	3.6
Bending Strength (Mpa)	70	65		0.90	0.820	0.58
Bending Modulus (Mpa)	23	31	0.02	27 – 0.030	0.02	0.03
Impact Strength (J)	2	8		0.29	0.3	0.25
Thermal Conductivity (W/m.K)	44	1.3		0.16	0.48211	0.48353
Dielectric Constant (ɛ́)		-		3.3	4.5	5.1
Properties	Alloy Steel	PVC Pi	pes	ER/PF/KI	F ER/PF/GI	F ER/PF/CF
Density (g/cm ³)	8.27	1.38		1.33	1.45	1.4
Tensile Strength (MPa)	420	52		105	93	261
Tensile Modulus (MPa)	200	3.0 – 3	.3	13.9	13.83	31.53
Maximum Strain to Failure	4-5.6	3-17	3-17 21		11.4	11.6
Bending Strength (Mpa)	765	0.90		0.7	1.180	2.020
Bending Modulus (Mpa)	231	0.027 - 0.030		0.053	0.047	0.095
Impact Strength (J)	28	0.29		2.15	1.25	0.7
Thermal Conductivity (W/m.K)	44.3	0.16		0.4911	0.4941	0.4972
Dielectric Constant (ἑ)	-	3.3		5.4	6.1	9.4

Table (4-9): Properties of plastic pipes material with ER/PF/nanoparticles and ER/PF/fibers.

Properties	Alloy Steel	PVC Pipes	ER/PF/KF/ MgO	ER/PF/GF/ MgO	ER/PF/CF/ MgO
Density (g/cm ³)	8.27	1.38	1.37	1.48	1.43
Tensile Strength (MPa)	420	52	101	63	255
Tensile Modulus (MPa)	200	3.0 - 3.3	14.2	9.5	31.03
Maximum Strain to Failure	4-5.6	3-17	22.3	10.2	5.32
Bending Strength (Mpa)	765	0.90	1.36	1.22	2.38
Bending Modulus (Mpa)	231	0.027 - 0.030	0.066	0.074	0.14
Impact Strength (J)	28	0.29	0.95	1.4	1.75
Thermal Conductivity (W/m.K)	44.3	0.16	0.4901	0.4931	0.4962
Dielectric Constant (ἑ)	-	3.3	4.1	4.3	6.6

Table (4-10): Properties of plastic pipes material with ER/PF/fibers/ nanoparticles.

Properties	Alloy Steel	PVC Pipes	ER/PF/KF/ ZrO	ER/PF/GF/ ZrO	ER/PF/CF/ ZrO
Density (g/cm ³)	8.27	1.38	1.4	1.5	1.45
Tensile Strength (MPa)	420	52	125	83	112
Tensile Modulus (MPa)	200	3.0 - 3.3	13.95	14	22.7
Maximum Strain to Failure	4-5.6	3-17	23.3	10.6	7
Bending Strength (Mpa)	765	0.90	0.86	0.84	0.54
Bending Modulus (Mpa)	231	0.027 - 0.030	0.05	0.076	0.038
Impact Strength (J)	28	0.29	1.6 J	1.25	1.4
Thermal Conductivity (W/m.K)	44.3	0.16	0.4891	0.4921	0.4952
Dielectric Constant (ἑ)	-	3.3	4.7	4.1	13.1

4.6.1.1 The Simulation Processes

It consists of two steps (form design) as shown in the steps as shown in the figure (4-47):



Figure (4-47): Steps for designing pipes in a program solid work.

The first step begins with making a model for the part to be designed using the solid work version (2016) program which contains tools for 3D drawing. A design map for a plastic pipe was obtained and using the program the model was drawn. When the model is finished drawing, it is saved in parasolid format so that the other program can read it.

4.6.1.2 The Second Step (Analyzing the Results):

The results were analyzed using the ANSYS program, starting the process by withdrawing the form from the solid work program to ANSYS by instructing import and choosing the Parasolid formula, and then starting the analysis with the following steps as shown in the figure (4-48):

1- The preprocessor, which consists of several steps:

- Define the model as (solid) [(element type) to (solid)].

- Define the material properties by entering the modulus of elasticity in addition to entering the Poisson's ratio.

- Make a mesh for the form.

2 -The solution consists of several steps:

- Install the parts that need to be installed.

- Load shedding (in this model, pressure is applied to the inner part of the model (0.035Mpa).

- Solve the form by using solve.

3- Getting results by using general postprocess and consists of several instructions:

plot results + contour plot + nodal solution, then we get stress results in addition to the results of the strain.



Figure (4-48): Steps for analysis the results of pipes in a program ANSYS.

4.6.2 Oil Pan in the Internal Combustion Engine

The oil container is one of the important internal combustion engine parts as shown in the figure (4-49), which was chosen to manufacture parts of the composite material that was manufactured in this research. In automotive applications, the internal combustion engines in the lower part contain the important part tightened by a large metal frying pan called oil pan. It holds engine oil and acts as an oil tank. While the engine is running, the oil pump pulls the oil out of the pan and spreads it through the engine, and the oil is allowed to return to the oil pan after it passes through the engine. It is a place to collect oil if the engine is stopped and also to collect impurities from the oil and allows the removal of old oil. It also cools the oil by passing air over the surface of the pan. Using an oil container requires the engine be installed slightly higher to make space for it. The oil pan is manufactured by aluminum alloy and is installed at the bottom of the crankcase and is a detachable mechanism. To maximize its function, it is formed with a deep drawing process, and is placed at the bottom of the engine to act as an oil tank. To protect the engine from damage, some oil tanks have one or more magnets designed to pick up small metal parts before you can connect the oil filter.





Figure (49): Oil pan and engine components.

For engine to work at its best, it must be running at a specific operating temperature. This temperature can only be maintained with the aid of engine oil that acts as a coolant. Subsequently, it needs a component to store the oil and continuously reuse it. Oil pan also served as a bottom cover of engines, cast aluminum alloy used as a material for the oil pan, and all the properties of the oil pan compared with composite material values are shown in the table (4-11) and (4-12).

Properties	Al-Alloy 2024- T361	PA66-GF35	ER/PF/ZrO	ER/PF/MgO
Density (g/cm ³)	2.8	1.41	1.25	1.23
Tensile Strength (MPa)	483	115	28	18
Tensile Modulus (MPa)	72	11	6.2	5.67
Maximum Strain to Failure (%)	13	3.05	9.1	3.6
Flexural Strength (Mpa)	-	1.1	0.820	0.58
Flexural Modulus (Mpa)	-	0.07168	0.02	0.03
Impact Strength (J)	-	1.38	0.3	0.25
Thermal Conductivity (W/m.K)	120	-	0.48211	0.48353

Table (4-11): Properties of oil pan material with ER/PF/nanoparticles and ER/PF/fibers.

Properties	Al-Alloy 2024- T361	PA66- GF35	ER/PF/KF	ER/PF/GF	ER/PF/CF
Density (g/cm ³)	2.8	1.41	1.33	1.45	1.4
Tensile Strength (MPa)	483	115	105	93	261
Tensile Modulus (MPa)	72	11	13.9	13.83	31.53
Maximum Strain to Failure (%)	13	3.05	21	11.4	11.6
Flexural Strength (Mpa)	-	1.1	0.7	1.180	2.020
Flexural Modulus (Mpa)	-	0.07168	0.053	0.047	0.095
Impact Strength (J)	-	1.38	2.15	1.25	0.7
Thermal Conductivity (W/m.K)	120	-	0.4911	0.4941	0.4972

Properties	Al-Alloy 2024-T361	PA66-GF35	ER/PF/KF/ MgO	ER/PF/GF/ MgO	ER/PF/CF/ MgO
Density (g/cm ³)	2.8	1.41	1.37	1.48	1.43
Tensile Strength (MPa)	483	115	101	63	255
Tensile Modulus (MPa)	72	11	14.2	9.5	31.03
Maximum Strain to Failure (%)	13	3.05	22.3	10.2	5.32
Flexural Strength (Mpa)	-	1.1	1.36	1.22	2.38
Flexural Modulus (Mpa)	-	0.07168	0.066	0.074	0.14
Impact Strength (J)	-	1.38	0.95	1.4	1.75
Thermal Conductivity (W/m.K)	120	-	0.4901	0.4931	0.4962

Table (4-12): Properties of oil pan material with ER/PF/fibers/ nanoparticles.

Properties	Al-Alloy 2024- T361	PA66- GF35	ER/PF/KF/ ZrO	ER/PF/GF/ ZrO	ER/PF/CF/ ZrO
Density (g/cm ³)	2.8	1.41	1.4	1.5	1.45
Tensile Strength (MPa)	483	115	125	83	112
Tensile Modulus (MPa)	72	11	13.95 MP	14 MP	22.7 MP
Maximum Strain to Failure (%)	13	3.05	23.3	10.6	7
Flexural Strength (Mpa)	-	1.1	0.86	0.84	0.54
Flexural Modulus (Mpa)	-	0.07168	0.05	0.076	0.038
Impact Strength (J)	-	1.38	1.6	1.25	1.4
Thermal Conductivity (W/m.K)	120	-	0.4891	0.4921	0.4952

4.6.2.1 The Simulation Processes



It consists of two steps (form design) as shown in the figure (4-50):

Figure (4-50): Steps for designing oil pan in a program solid work.

The first step begins with making a model for the part to be designed using the solid work version (2016) program which contains tools for 3D drawing. A design map for a plastic pipe was obtained and using the program the model was drawn as shown in the steps. When the model is finished drawing, it is saved in parasolid format so that the other program can read it.

4.6.2.2 The Second Step (Analyzing the Results):

The results were analyzed using the ANSYS program, starting the process by withdrawing the form from the solid work program to ANSYS by instructing import and choosing the Parasolid formula, and then starting the analysis with the following steps as shown in the figure (4-51) and (4-52):

1- The preprocessor, which consists of several steps:

- Define the model as (solid) [(element type) to (solid)].

- Define the material properties by entering the modulus of elasticity in addition to entering the Poisson's ratio.

- Make a mesh for the form.

2 -The solution consists of several steps:

- Install the parts that need to be installed.

- Load shedding (in this model, pressure is applied to the inner part of the model (0.035Mpa).

- Solve the form by using solve.

3- Getting results by using general postprocess and consists of several instructions:

plot results + contour plot + nodal solution, then we get stress results in addition to the results of the strain.





Figure (51): Steps for analyzing the results of oil pan in a program ANSYS.

Max. stress = 115.303Mpa

Max. deformation = 0.068922mm.



Figure (52): Steps for analyzing the results of oil pan in a program ANSYS.



5.1 Conclusions

1- The effect of different mixing ratios on the mechanical and physical properties of the composite material including ER and PF resins, where there an improvement in mechanical properties at low mixing ratios of (5%) and (10%) PF in tensile strength, bending and impact with good hardness.

2- The physical and mechanical properties of composite materials include ER and PF resins improve when reinforcement with MgO and ZrO nanoparticles compared with nonreinforced composite materials including ER and PF resins.

3- Improve the mechanical and physical properties of composite materials includes ER and PF resins when reinforced with GF, CF, KF fibers compared with nonreinforced composite materials including ER and PF resins.

4- Significant improvement in mechanical and physical properties of composite materials includes ER and PF resins when reinforced with MgO and ZrO nanoparticles and GF, CF, KF fibers compared with nonreinforced composite materials including ER and PF resins.

5- Comparing the teste result of composite materials with the standard specifications for plastic pipes and oil pan for internal combustion engines and their applications through the finite elements method (FEM). The best results for ER/PF/Mg/CF, ER/PF/ZrO/GF and ER/PF/CF in the applications of oil pan and ER/PF/Mg/GF, ER/PF/GF and ER/PF/KF in plastic pipe applications.

5.2 Future Recommendations

1- Study of the effect of grains size of composite materials reinforced by nanoparticles for on the mechanical and physical properties with different fibers.

2- The environmental effect of sunflower husk residues and dates nucleus residues to produce an environmentally friendly composite materials that contribute to the sustainability of natural resources.

3- Study of the effect of flame retardants on the properties of composite materials reinforced by fibers, nanoparticles and microparticles.

4- Study of the effect of mechanical properties such as "creep testing, fatigue testing, fracture toughness testing and etc." on composite materials including epoxy, phenol formaldehyde and different mixing ratios reinforced by fibers and nanoparticles.

5- Study of the effect of physical properties such as "electrical volume and surface resistivity, cure behavior by DMA, moisture conditioning, fracture toughness testing and etc." on composite materials including epoxy, phenol formaldehyde and different mixing ratios reinforced by fibers and nanoparticles.

6- Study of the effect of shape, distribution and volume fraction of nanoparticles and the fibers-reinforced composite materials.

7- Study of the effect of lamination volume (number of fibers laminates) and their direction on the physical and mechanical properties of composite materials including epoxy and phenol formaldehyde.

8- Study and apply of the results of the composite materials with other applications by comparing them with their standard specifications and obtaining alternative composite materials of high quality.



1- A. Asbty, D. Jones, "Engineering Material, an Introduction to Microstructure Processing and Design", Pergamon Press, England, (1986).

2- W. Gaylord, "Reinforced Plastics Theory and Practice", Cahners Publishing Co. Inc., USA, (1974).

3- D. Hull, "An Introduction to Composites Materials", Cambridge University Press, U.K., (1981).

4- M. P. Groover, "Fundamentals of Modern Manufacturing: Materials", Processes and Systems, Wiley and Sons, USA, (2010).

5- B. Harris, "Engineering Composite Materials", The Institute of Materials, London, p. 5, (1999).

6- L. F. Nielsen, "Composite Materials", Springer-Verlag, Berlin Heidelberg, p. 14, (2005).

7- W. D. Callister, "Fundamentals of Materials Science and Engineering", 5th edition, John Wiley & Sons, Inc., New York, p. 726, (2001).

8- K. Sethi, "Investigation of damaged glass fiber reinforced polymer composites in 3-point bending", Master's Thesis, India, (2004).

9- M. Rubein and R. H. Colby, "Polymer Physics", Oxford University Press, USA, (2003).

10- J. P. Pascault and R. J. J. Williams, "Epoxy Polymers", WILEY-VCH Verlag GmbH and Co. KGaA, Weinheim, Germany, (2010).

11- D. Chondhury and A. Thompson, "Introduction to Materials Science", University Tennessee, USA, (2006).

12- C. Zweben, "Handbook of Plastics, Elastomers and Composites", McGraw-Hill Companies, USA, p.321, (2004).

148

13- S. Knop and W. Scheib, "Chemistry and Application of Phenolic Resin", Springer-Verlag, Berlin Heidelberg, New York, (1979).

14- K. L. Forsdyke, "Phenolic Matrix Resins – The Way to Safer Reinforced Plastics", 43rd Annual Conference, Composites Institute, SPI, February, (1988).

15- NIIR Board, "Polymers and Plastics Technology Handbook", Publisher: Asia Pacific Business Press Inc., (2006).

16- M. S. Bhatnagar, "Polymer", Chemistry and Technology of Polymer, Condensation Polymers, Chand S. and Company LTD New Delhi, vol. 3, (2004).

17- W. Perkins, A. Marcell and J. Frerking, "Journal of Applied Polymer Science", vol.43, no. 2, pp. 329-349, (1991).

18- M. I. Aziz, "Plastic Chemistry", Nava University, (1993).

19- A. Leszek, "Polymer Alloys and Blends", Thermodynamics and Rheology, Hanser publishers, New York, (1989).

20- MIL -HDBK-75(AR), "Plastic Matrix Composites with Composites with Continuous Fiber Reinforcement", USA, p. 3, (1991).

21- R. M. Christensen and J. McCoy, "Mechanics of Composite Materials", Journal of Applied Mechanics, (1980).

22- M. Francis and L. King, "Fundamentals and Basics of Composite Materials - A Review", Proceedings of the National Conference on Recent Trends in Engineering Sciences 2k11, (2011).

23- S. Thomas and K. Joseph, "Polymer Composites", vol. 1, 1st ed., Wiley-VCH Verlag GmbH & Co. KGaA. Weinheim, (2012). 24- P.A. Thornton and V. J. Colangdo, "Fundamentals of Engineering Materials", Prentice- Hall, New Jersey, (1985).

25- M. Andrew and K. Chalwla, "Mechanical Behavior of Materials", Prentice, Hall, New Jersey, (1999).

26- K.L. Edwards, "An Overview of the Technology of Fiber-Reinforced Plastics for Design Purposes", Mat. and Design, vol.19, pp. 1-10, (1998).

27- M. Kuwata, "Mechanisms of Interlaminar Fracture Toughness using Non-Woven Veils as Interleaf Materials", Ph.D. thesis, University of London, (2010).

28- G. Dorey, "Impact properties of Carbon Fiber/Kevlar 49 Fiber Hybrid Composites", Science Direct Journal, vol. 9, Issue 1, pp. 25-32, January, (1978).

29- B. V. Perov and I. P. Khoroshilova, "Hybrid composite materials", Springer, Dordrecht, vol. 4, Issue 1, pp. 269-304, (1995).

30- X. Chen, and S. S. Mao, "Titanium Dioxide Nanomaterials: Synthesis, Properties, Modifications, and Applications", Chem. Rev. 107, pp. 2891-2959, (2007).

31- W. R. Fahrner "Nanotechnology and Nanoelectronics Materials, Devices, Measurement Techniques", Springer-Verlag Berlin Heidelberg, (2005).

32- R. Kochetov, "Thermal and Electrical Properties of Nanocomposites", Including Material Processing, p.197, (2012).

33- J. H. Koo, "Polymer Nanocomposite, Processing, Characterization and Application", Mc. Graw Hill Companies, USA, (2006).

34- R. N. Rothon, "Particulate-Filled Polymer Composites", Rapra Technology Limited, (2003).

35- K. J. Klabunde, "Nanoscale Materials in chemistry", john G, (2001).

36- G. Zhang, "Dispersion structure and properties of Nanocomposites", M.Sc. thesis, Department of Chemical and Materials Engineering, University of Cincinnati, USA, (2009).

37- J. Wang, X.G. Hu, M, Tian and R. Stengler, "Study on Mechanical and Tribological Property of Nanometer Zro₂ filled Polyoxymethylene Composites", Polymer-Plastics Technology and Engineering, 46, pp. 469–473, (2007).

38- D. S. BAE, E. J. KIM, S. W. PARK and K. S. HAN, "Synthesis and Characterization of Nanosized ZnxMn1-xFe2O₄ Powders by Glycothermal Process", Mater Sci Foru, 486, pp. 436–439, (2005).

39- J. S. Kim, D. H. Lee, S. Kang, D. S. Bae, H. Y. Park, and M. K. Na, "Synthesis and Microstructure of Zirconia Nanopowders by Glycothermal Processing", Trans. Nonferrous Met. Soc. China, English Ed., vol. 19, pp. 16–19, (2009).

40- D. Mehta and R. Shetty, "Bonding to Zirconia: Elucidating the Confusion", Int. Dent. SA, vol. 12, no. 2, pp. 7–46, (2010).

41- A. Arena and F.Prete, "Nanostructured Zirconia-Based Ceramics and

Composites in Dentistry", Nanomaterials, vol. 9, no. 2, pp. 1–14, (2019).

42- A. Note, "Temperature-Dependent Phase Transitions of ZrO₂", Materials Design, pp. 1–4, (2009).

43- A. Mahshad, J. Mona and R. Alimorad, "Simple and Economical Method for the Preparation of MgO Nanostructures with Suitable Surface Area", vol. 33, no. 1, pp. 21–28, (2014).

44- H. Zulkefle, L. N. Ismail and R. A. Bakar, "Enhancement in Dielectric Constant and Structural Properties of Sol-Gel Derived MgO Thin Film using ZnO/MgO Multilayered Structure", vol. 2, no. 1, (2012).

45- S. Ray, "Processing and Characterization of Titania Filled Epoxy-Glass Fiber Composites", Master's Thesis, Rourkela, (2009).

46- W.F. Smith and J. Hashemi, "Foundation of Material Science and Engineering", 4th ed., McGraw –Hill Comp.Inc., USA, p. 695, (2006).

47- P.K. Mallick, "Fiber Reinforced Composites Materials, Manufacturing and Design", Taylor & Francis Group, LLC, USA, p. 198, (2008).

48- R. W. Cahn, E. A. Davis and I. M. Ward, "Microstructural Design of Fiber Composites", Cambridge University Press, UK, p. 29, (1992).

49- K. Jang, "Engineered Interfaces in Fiber Reinforced Composites", Elsevier Science Ltd, Netherlands, p. 7, (1998).

50 - A.V. Pocius and D.A. Dillard, "Adhesion Science and Engineering – 2, The Mechanics of Adhesion", Elsevier Science B.V., The Netherland, p. 1011, (2002).

51- S. T. Peters, "Handbook of Composites", 2nd ed., Chapman and Hall, Cambridge University Press, UK, p. 34, (1998).

52- P.M. Ajayan and L.S. Schadler, "Nanocomposites Science and Technology", Wiley-VCH Verlag GmbH & Co. KGaA., Weinheim, (2003).
53- H. Z. Shishan, and J. Shen, "Polymer/Silica Nanocomposites: Preparation, Characterization, Properties, and Applications", Chem. Rev. 108, pp. 3893– 3957, (2008).

54- E. Grades, "Functionalization and Immobilization of MgO Nanocubes", Dipl.-Ing. Andreas Sternig, (2012).

55- D. Devaprakasam, P.V. Hatton and B.J. Inkson, "Effect of Microstructure of Nano- And Micro-Particle Filled Polymer Composites on their Tribo-Mechanical Performance", Journal of Physics, Conference Series 126, 012057, (2008).

56- S. P. Thomas, R. Stephen and S. Thomas, "Polymer Nanocomposites: Preparation, Properties and Applications", Research Gate, vol. 2, pp.49-56, (2007).

57- J. Yuan, S. Zhow, G.Gu and L.Wu, "Effect of Particles Size of Nanosilica on Performance of Epoxy/Silica Composites Coatings", Journal of Materials Science 40, pp. 3927-3932, (2005).

58- M. Cakir, I. Kartal, and R. Samur, "Effect of Water Absorption on the Wear Behavior of Sol-Gel Processed Epoxy/Silica Hybrids", Scientific Research and Essays, vol. 7, pp. 805-812, (2012).

59- M.L. G. Curiel, "Polymer – Inorganic Nanocomposites: Influence of Colloidal Silica", The Netherlands, (2004).

60- R. Nagalingam, S. Sundaram and B. S. J. Retnam, "Effect of Nanoparticles on Tensile, Impact and Fatigue Properties of Fiber Reinforced Plastics", Bull. Mater. Sci, vol. 33, no. 5, pp. 525-528, (2010).

61- C. M. Manjunatha, A. C. Taylor and A. J. Kinloch, "The Tensile Fatigue Behavior of a Silica Nanoparticle-Modified Glass Fibre Reinforced Epoxy opposite", Composites Science Technology, vol. 70, pp. 193-199, (2010).

62- D. Lingaraju, K. Ramji and U. Lakshmi, "Mechanical and Tribological Studies of Polymer Hybrid Nanocomposites with Nano Reinforcements", Eng. & Technology, vol. 34, no. 4, pp. 705-712, (2011).

63- K. Devendra and T. Rangaswamy, "Evaluation of Thermal Properties of E-Glass, Epoxy Composites Filled by Different Filler Materials", International Journal of Computational Engineering Research, vol. 2, no. 1, pp. 1708–1714, (2012).

64- T. Rajmohan and U.K. Koundinya, "Evaluation of Mechanical Properties of Nano Filled Glass Fiber Reinforced Composites", IEEE Xplore, vol. 2, no. 1, pp. 358–365, (2013).

65- A. A. Wereszczak, T. G. Morrissey, C. N. Volante, P. J. Farris, R. J. Groele, R. H. Wiles, and H. Wang, "Thermally Conductive MgO -Filled Epoxy Molding Compounds", IEEE Trans. Components, Packag. Manuf. Technol., vol. 3, no. 12, pp. 1994–2005, (2013).

66- B. H. Manjunath and K. P. Rao, "Influence of Fiber/Filler Particles Reinforcement on Epoxy Composites", International Journal of Engineering Research and Applications (IJERA), vol. 3, no. 1, pp. 1147-1151, (2014).

67- Y. Haribabu and P. D. Prasad, "Effect of Nanoparticles on E-Glass Fiber Epoxy Resin Composites", International Open Access Journal of Modern Engineering Research, vol. 5, no. 1, pp. 65–69, (2015).

68- A. Mohanty and V. K. Srivastava, "Effect of Alumina Nanoparticles on the Enhancement of Impact and Flexural Properties of the Short Glass/Carbon Fiber Reinforced Epoxy Based Composites", Springer, Fibers and Polymers, vol. 16, no. 1, pp. 188–195, (2015).

69- P. Banakar, H. K. Shivananda and H. B. Niranjan, "Influence of Fiber Orientation and Thickness on Tensile Properties of Laminated Polymer Composites", International Journal of Pure and Applied Sciences and Technology, vol. 9, no. 9, pp. 61–68, (2016).

70- O. Y. Bozkurt, W. K. Al-Azzawi and O, Ozbek, "The Effect of Nano Silica on Tensile and Flexural Behavior of Glass Fiber Reinforced Composite Laminates", Proceedings of Academics World International Conference, Lisbon, Portugal, vol. 8, no. 2, pp. 8–11, (2017).

71- A. Batabyal, R. K. Nayak and S. Tripathy, "Evaluation of Mechanical Properties of Glass Fibre and Carbon Fibre Reinforced Polymer Composite", Journal of Communication Engineering & Systems, vol 8, no 2, (2018).

72- M. Bulut, M. Alsaadi and A.Erkliğ, "A Comparative Study on the Tensile and Impact Properties of Kevlar, Carbon, and S-Glass/Epoxy Composites Reinforced with Sic Particles", Materials Research Express, vol 5, (2018).

73- F. Ahmadijokani, Y. Alaei, A. Shojaei, M. Arjmand and N.Yan, "Frictional Behavior of Resin-Based Brake Composites: Effect of Carbon Fibre Reinforcement", Science Direct, vol. 420-421, pp. 108-115, (2019).

74- W. D. Callister Jr. and D. G. Rethwisch, "Fundamentals of Materials Science and Engineering an Integrated Approach", Third edition, John Wiley and sons Inc., (2008).

75- Z. D. Jastrzebski, "The Nature and Properties of Engineering Materials", John Wiley and sons, Inc., (1976).

155

76- L. E. Nielsen and R. F. Landel, "Mechanical Properties of Polymers and Composites", Marcel Dekker, Inc., (1994).

77-W. Soboyejo, "Mechanical Properties of Engineered Materials", Marcel Dekker, Inc., (2002).

78- D. Gross and T. Seelig, "Fracture Mechanics with an Introduction to Micromechanics", Springer Verlag Berlin Heidelberg, (2006).

79- A. S. Khleel, "Study the Effect of Additives on some Mechanical and Thermal Properties for Epoxy Resin", Ph. D. Thesis, Department of Physics, University of Baghdad, Iraq, (2007).

80- N. Perez, "Fracture Mechanics", Kluwer Academic Publishers Boston, (2004).

81- W. F. Hosford, "Mechanical Behavior of Materials", William F. Hosford, (2010).

82- A. F. Liu, "Mechanics and Mechanisms of Fracture: An Introduction", ASM International, (2005).

83- S. L. kakapli and A. kakani, "Material Science and Engineering", New Age International (P) Ltd., (2004).

84- J. F. Shackelford, "Introduction to Material Science and Engineering", USA, (2005).

85- A. Basarkar and J. Singh, "Poly (Lactide-Co-Glycolide)-Polymethacrylate Nanoparticles for Intramuscular Delivery Plasmid Encoding Interleukin Co. to Prevent Autoimmune Diabetes in Mice", Journal of Pharmaceutical Research, vol. 26, no. 1, pp. 72-81, (2009).

156

86- P. Schreurs, "Fracture Mechanics", Lecture Notes - Course 4A780 Concept Version, (2012).

87- V. V. Vasiliev and E. V. Morozov, "Mechanics and Analysis of Composite Materials", Elsevier Science Ltd., (2001).

88- D. R. Moore, "The Application of Fracture Mechanics to Polymers, Adhesives and Composite", Elsevier Ltd. and Esis, (2004).

89- M. Ward and J. Sweeney, "An Introduction to the Mechanical Properties of Solid Polymers", John Wiley and Sons Ltd., (2004).

90- G. H. Michler and F. J. Balta-Calleja, "Mechanical Properties of Polymers Based on Nanostructure and Morphology", Taylor and Francis Group, (2005).

91- S. Kumar and W. A. Curtin, "Crack interaction with microstructure", vol. 10, no. 9, (2007).

92- J. K. Nelson, "Dielectric Polymer Nanocomposites", Springer Science and Business Media, (2010).

93- D. B. Sirdeshmukh, L. Sirdeshmukh and K.G. Subhadra, "Micro- and Macro-Properties of Solids: Thermal, Mechanical and Dielectric Properties", Springer-Verlag Berlin Heidelberg, (2006).

94- D. R. Askeland and P. P. Fulay, "Essentials of Materials Science and Engineering", Cengage Learning, (2009).

95- A. Harper, "Plastics Testing Technology", John wielly and Sons, London, (1984).

96- R. L. Ellis, "Ballistic Impact Resistance of Graphite Epoxy Composites with Shape Memory Alloy and Extended Chain Polyethylene Spectra", Master of Science in Mechanical Engineering, p. 4, (1996).

157

97- S.L. kakani and A. kakani, "Material Science", New Age International (p) Ltd. publishers, (2004).

98- I. R. H. D. Hardness, "Shore Hardness Testing", Innova Test, P. 124-137, (1988).

99- J. M. Jewell, M. S. Spess, and R. L. Ortlano, "Effect of Heat-Treatment Temperature on the Properties of Lithium Alumina-silicate Glass", Journal of American Society, vol. 74, pp. 92-97, (1991).

100- H. Semat and R. Katz, "Capacitance and Dielectrics", University of Nebraska-Lincoln, Rober Katz Publication, USA, (1958).

101- A. Agrawal and A. Satapathy, "Thermal, Mechanical and Dielectric Properties of Aluminium Oxide and Solid Glass Microsphere-Reinforced Epoxy Composite for Electronic Packaging Application", Wiley Online Library, (2009).

102- K. C. Kao, "Dielectric Phenomena in Solide", Elsevier, Inc., (2004).

103- P. J. Harrop, "Dielectrics", Butterworth and Co., (1972).

104- K. A. Krishnamuthy and M. R. Raghuveer, "Electrical and Electronics Engineering", Wiley Eastern, Canada, (1993).

105- B. S. Mitchell, "An Introduction to Materials Engineering and Science", John Wiley and Sons Inc., New Jersey, USA, (2004).

106- B. Brown, D. Hess, V. Desai and M. Jamal Deen, "Dielectric Science and Technology", The Electrochemical Society Interface, Spring, (2006).

107- C. P. Smyth, "Dielectric Behavior and structure", Princeton University, (1955).

108- S. C. Tjong and Y. W. Mai, "Physical Properties and Applications of Polymer Nanocomposites", Woodhead Publishing Limited, (2010).

109- R. E. Newnham, "Properties of Materials Anisotropy, Symmetry, Structure", Oxford University Press, (2005).

110- W. Liu, S. Hoa and M. Pugh, "Fracture toughness and Water Uptake of High-Performance Epoxy/Nanoclay Nanocomposites", Compos. Sci. Tech. 65, pp. 2364–2373, (2005).

111- K. F. Young and H. P. R. Frederikse, "Compilation of Static Dielectric Constant of Inorganic Solids", Institute for Materials Research, vol. 2, no. 2, (1973).

112- B. Tareev, "Physics of Dielectric Materials", Mir publisher, Moscow, (1979).

113- D. D. L. Chung, "Materials for Electronic Packaging", Butterworth-Heinemann, (1995).

114- Y. K. Godovsky, "Thermo-physical Properties of Polymers", Springer-Verlag, (1992).

115- Y. Yang, "Thermal conductivity, Physical properties of polymers". Handbook, edited by J.E. Mark, Chapter 10, 2nd ed., Springer, (2007).

116- H.S. Tekce, D. Kumlutas and I.H. Tavman, "Effect of Particle Shape on Thermal Conductivity of Copper", (2007).

117- D. Hansen and G. A. Bernier, "Thermal Conductivity of Polyethylene: The Effect of Crystal Size, Density and Orientation on the Thermal Conductivity", Polymer Engineering and Science, vol. 12, no. 3, pp. 204-208, (1972). 118- W. N. dos Santos, J.A. de Sousa and R. Gregorio Jr., "Thermal Conductivity Behavior of Polymers Around Glass Transition and Crystalline Melting Temperatures", Polymer Testing 32, pp. 987–994, (2013).

119- S. S. Mustafa, "Weathering Effect on Mechanical, Optical and Surface Properties of Unsaturated Polyester and Epoxy Resin Matrix Composites", University of Baghdad, College of Science, (1997).

120 A. Anthony and D. Sims, "Weathering of Polymers ", Applied Science Publishers London and New York, (1983).

121- W. R. Broughton and M. J. Lodeiro, "Techniques for Monitoring Water Absorption in Fiber-Reinforced Polymer Composites", Materials Npl. Co. Uk, (2000).

122- P. Bonniau and A. R. Bunsell, "Water Absorption Theories Applied to Glass Epoxy Composites", J. Composite Materials, vol. 15, pp. 272, (1981).

تم خلط الأيبوكسي مع الفينول فورمالديهايد بنسب وزنية مختلفة وهي (%0,5,10.15,20,30,40,50)، و تم الحصول من خلال الاختبارات الميكانيكية و الفيزيائية على الخليط الأمثل95%ER/5%PF وتدعيمه بواسطة الجسيمات النانوية ZrO و MgO بكسر وزني (%1) و من ثم تم تدعيمه بالألياف GF و KF و CF و اخيرا تدعيمه بالجسيمات النانوية ZrO و MgO بكسر وزني (%1) مع الألياف GF و FJ و KF و (%1) تدعيمه بالجسيمات النانوية ZrO و MgO بكسر وزني (%1) مع الألياف GF و FJ و الخيرا لدراسة لتأثير الخصائص الميكانيكية (اختبار الشد و اختبار الانحناء و اختبار الصدمة و الصلادة) و الخصائص الفيزيائية (التوصيلية الحرارية، اختبار العزل الكهربائي، اختبار الامتصاص).

تتحسن الخصائص الميكانيكية لـER/PF في اختبار قوة الشد مع زيادة تركيز PF، و عند الكسر الوزني (5%) تم الحصول على أقصى قدر من التحسن في قوة الشد بمقدار (%1.2). زادت قوة الشده عند (%20) تم الحصول على أقصى قدر من التحسن في قوة الشد بمقدار (%3.2). زادت قوة الشده عند (%36.3) و عند ER/PF/MgO كانت الزيادة الكبيرة بقوة الشد بحوالي (%936.3)، و كانت أفضل نتيجة لقوة الشد هي عند ER/PF/MgO/CF بنسبة أكبر من ER/PF.

كانت نتائج اختبار قوة الانحناء واختبار معامل الانحناء ل ER/PF هي الأفضل عند المتراكب 90%ER/10%PF في قيمة الاجهاد، و عند زيادة الكسر الوزني أصبحت قيمة الاجهاد أقل، و عند المتراكب ER/PF/ZrO زادت قيمة الإجهاد (300%) عن 90%ER/10%PF، و عند تدعيم ER/PF بالألياف تم الحصول على أفضل نتيجة عند ER/PF/CF بالمقارنة مع ER/PF/GF و ER/PF/KF. عند تدعيم ER/PF مقارنة بالألياف والجسيمات النانوية نحصل على قيمة إجهاد ثلاث مرات اكبر و خصوصا عندFR/DgO/CF مقارنة مع ER/PF المدعم بالألياف أو الجسيمات النانوية.

نلاحظ زيادة قوة الصدمة مع زيادة الكسر الوزني ER/PFJ لتبلغ اعلى قيمة لها عند95%ER/5%PF، بعد ذلك تنخفض قوة الصدمة مع زيادة الكسر الوزني، ومن ثم اضافة الجسيمات النانوية MgO و ZrO ادى الى زيادة قوة الصدمة و أفضل نتيجة كانت عند ER/PF/MgO بفارق كبير عن 95%ER/5%PF، من ناحية أخرى و جد ان ER/PF/KF يزيد من قوة الصدمة عن لـ PS%ER/5%PF. نلاحظ زيادة قيمة قوة الصدمة لا ER/PF/KF يزيد من قوة الصدمة عن لـ RC% و ZrO مع الألياف المختلفة، حيث ان ER/PF/MgO/KF يمتلك اعلى قيمة من قوة الصدمة.

تم أخذ النتيجة المثلى لاختبار الصلابة و هي ER/5% PF %95% لتدعيمها مع الجسيمات النانوية والألياف، وكانت أفضل نتيجة هي ER/PF/MgO و ER/PF/MgO/GF وER/PF/MgO/GF.



أظهر سلوك التوصيلية الحرارية لER/PF النتيجة المثلى عند 95%ER/5%PF و نقل التوصيلية الحرارية عند 80%ER/20%PF. عند اضافة الجسيمات النانوية لER/PF فان اعلى توصيلية حرارية وجدت عند. ER/PF/ZrO و اوطئ توصيلية حرارية وجدت عند. ER/PF/MgO. عند اضافة الألياف لER/PF فان اعلى توصيلية حرارية وجدت عند ER/PF/KF و اوطئ توصيلية حرارية وجدت عند اختافة الألياف ER/PF. ان تدعيم ER/PF بالألياف و الجسيمات النانوية ادى الى الحصول على اعلى قيمة للتوصيلية الحرارية وكانت عند ER/PF/ZrO, و اوطرك وكانت عند

وجد ان اعلى قيمة لثابت العازل الكهربائي و الفقد العزلي الكهربائي عند 80%ER/20%PF و اعلى قيمة للتوصيلية الكهربائية المتناوبة عند 95%ER/5%PF، و عند تدعيم ER/PF بالالياف نحصل على أعلى قيمة لثابت العزل الكهربائي والفقد العزلي الكهربائي و التوصلية الكهربائية المتناوبة عند R/PF/CF بالمقارنة مع لثابت العزل الكهربائي والفقد العزلي الكهربائي و التوصلية الكهربائية المتناوبة عند R/PF/CF بالمقارنة مع الثابت العزل الكهربائي والفقد العزلي الكهربائي و التوصلية الكهربائية المتناوبة عند R/PF/CF بالالياف نحصل على أعلى الثابت العزل الكهربائي والفقد العزلي الكهربائي و التوصلية الكهربائية المتناوبة عند R/PF/CF بالمقارنة مع ER/PF/GF و R/PF/KF و R/PF/KF و R/PF/KF و R/PF/KF و الملى قيمة لثابت العزل الكهربائي عند ER/PF/ZrO و المعادية مع ER/PF/MgO و العلى قيمة لثابت العزل الكهربائي عند ER/PF/MgO و المعادية مع عند توصيلية كهربائية لمتناوبة عند ER/PF/MgO و الكهربائي عند ER/PF/MgO و الكهربائي و الفقد العزلي الكهربائي من ثابت عزل و عامل فقد و توصيلية كهربائية متناوبة عند التدعيم بالجسيمات النانوية و الالياف و خصوصا على الكهربائي الكهربائي و الكهربائي و الفوسينية و العلى قيمة لثابت العزل الكهربائي الكهربائي الكهربائي عند ER/PF/ZrO و المعان توصيلية كهربائية متناوبة عند التدعيم بالجسيمات النانوية و الالياف و خصوصا عاد الكهربائي من ثابت عزل و عامل فقد و توصيلية كهربائية متناوبة عند التدعيم بالجسيمات النانوية و الالياف و خصوصا عند ER/PF/MgO/CF و ER/PF/ZrO/CF و ER/PF/ZrO/CF و ER/PF/ZrO/CF

اظهرت نتائج اختبارات امتصاص الماء ان ER/PF/MgO الاكثر امتصاصا للماء و زاد امتصاص الماء عند تدعيمه باستخدام الجسيمات النانوية ER/PF/MgO و ER/PF/ZrO. كشفت النتائج التجريبية أن ER/PF/KF ذو قيمة عالية بامتصاص الماء، و تدعيم ER/PF مع الجسيمات النانوية و الألياف و خصوصا عند ER/PF/KF و ER/PF/MgO/KF ادى الى امتصاص المزيد من الماء.

تم مقارنة نتائج الاختبارات للمتراكبات كافة مع المواصفات القياسية لتطبيقات الانابيب البلااستيكية و حوض الزيت لمحركات الاحتراق الداخلي و تطبيقها من خلال برنامج تحليل العناصر المحدودة (FEA) و هو محاكاة للتطبيقات العملية باستخدام التقنية العددية التي تسمى طريقة العناصر المحددة (FEM). و كانت افضل النتائج للمتراكب ER/PF/Mg/CF في تطبيقات حوض الزيت و للمتراكب ER/PF/Mg/GF في تطبيقات الانابيب البلاستيكية.



تقييم الخواص الفيزيائية للألياف المدعمة للمتراكبات النانوية الهجينة و تطبيقاتها

من قبل **ماهر ناظر عبدالله** ماجستير علوم فيزياء 2015 م إشراف

أ.د. صباح انور سلمان أ.م.د. مصطفى احمد رجب

▲ 1442

2020 م