Studying mechanical and physical properties for polymer composite material reinforced by metal powders

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BY

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CERTIFICATE

This is to certify that the thesis entitled (Studying Mechanical and Physical Properties for Polymer Composite Material Reinforced by Metal Powders) submitted by Safaa Nayyef Abdul Jabbar , Roll no. 601002009, in the partial fulfillment for the award of degree of M.Tech in Materials& Metallurgical Engineering from the School of Physics & Materials Science, Thapar University, Patiala, is a record of candidates own work carried out by his under our supervision and guidance. The experimental matter embodied in this report has not been submitted in part or full for credit towards any other degree at Thapar University, Patiala or any other university.

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Safaa Nayyef AbdulJabbar

DECLARATION

I hereby declare that the thesis entitled "Studying mechanical and physical properties for polymer composite material reinforced by metal powders" is the work carried out by me under the supervision of Dr. Dwijendra P. Singh and Dr. Sihama Salih I have not submitted this work anywhere else for the award of my degree.

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ABSTRACT

This research covers reinforcement of unsaturated polyester resin, and studying some of their mechanical and physical properties. The samples were prepared by hand lay-out technique. The unsaturated polyester resin was reinforced by two groups of metal powders (Cu and Al) at selected weight percentage of (0, 5, 10. 15, 20 and 25) %. The study of mechanical properties includes the study of tensile properties (stress at breaking point, elastic modulus and ductility) and bending elastic modulus, impact properties and hardness. The physical properties include studying thermal conductivity for all the prepared samples. The results show a noticeable increase in values of tensile stress at fracture point, tensile modules stress at fracture point, tensile modules of elasticity, hardness as the weight fraction of metal powder increase and reach to maximum value at 15 % wt for both groups. Bending modulus is increased at all percentages of weight fraction of Al powder except at 5 %, it decreases slightly and also for all percentages of weight fraction of Cu powder except it increases in polymer composite for 10 %. Impact strength is decreased as the weight fraction of metal powder is increased for both groups. The study of physical test shows that thermal conductivity increases with the increase of weight percentage of metal powder for both groups. The agglomeration increases with increase of weight percentage for each type of composite.

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LIST OF ABBREVIATIONS

ABBREVIATION	CLARIFICATION
Al	Aluminum
ASTM	American society for Testing and Materials
At. wt	Atomic weight
BMI	Bismaleimides
Cu	Copper
CMCs	Ceramic matrix composites
EDX	Energy dispersive x-ray analysis
HDPE	High density polyethylene
ISO	International Organization for Standardization
LDPE	Low density polyethylene
MMCs	Metal matrix composites
OM	Optical Microscope
PP	Polypropylene
PC	Polycarbonate
PEEK	Polyetheretherketon
PPS	Polyphenylene sulphide
PMCs	Polymer matrix composites
PC	Polycarbonate
SiC	Silicon carbide
TiB2	Titanium boride
Tg	Glass transition temperature
UPR	Unsaturated polyester resin
ZrO2	Zirconium oxide

LIST OF NOMENCLATURES

SYMBOL	DESCRIPTION
G_c	Impact strength
U_c	The required energy for fracture
kc	Fracture toughness
E	Young Modulus
K	Thermal Conductivity
$\sigma_{frac.}$	Fracture stress
E_b	Bending modulus
Wt	Weight percentage
X	Magnification power
W	Watt
m	Meter
^oC	Celsius (centigrade)

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1.1Introduction

The concept of composites was not invented by human beings, it is found in nature. An example is wood, which is a composite of cellulose fibers in a matrix of natural glue called lignin. The shell of invertebrates, such as snails and oysters, is an example of a composite. Such shells are stronger and tougher than man-made advanced composites. In India, Greece, and other countries, husks or straws mixed with clay have been used to build houses for several hundred years. Mixing husk or sawdust in a clay is an example of a particulate composite and mixing straws in a clay is an example of a short fiber composite. These reinforcements are done to improve performance [1,2].

A composite material is made by combining two or more materials to give a unique combination and superior properties that cannot be met by conventional monolithic materials, such as metal and its alloys, ceramics, and polymers. Composites may have different properties that its constituents do not possess [1,3].

Composite materials have several advantages over traditional engineering materials, which make them attractive for many industrial applications. Composite materials have superior mechanical properties like high specific stiffness, high specific strength, high fatigue strength, and good impact properties. Polymer composite unlike most metallic materials, they may have high corrosion and chemical resistance. Besides, composite materials provide good dimensional stability and design flexibility, they are appropriate for near-net-shape processing, which eliminate several machining operations and thus reduces process cycle time and cost. Although composites could offer many beneficial properties, they suffer from the following disadvantages: compared to most of the traditional engineering materials, material cost of the composite materials is high, their high-volume production methods limit the widespread use of composites. A problem with polymer matrix composites is that they absorb serious amounts of moisture, which affects the mechanical properties and dimensional stability of the components. The high temperature resistance and solvent resistance depend strongly on the matrix material [1,4].

Composite materials have been utilized to solve technological problems for a long time but only in the 1960s did these materials start capturing the attention of industries with the introduction of polymeric-based composites. Since then, composite materials have become common engineering materials and are designed and manufactured for various applications including automotive components, sporting goods, aerospace parts, consumer goods, and in the marine and oil industries. The growth in composite usage also came about because of increased awareness regarding product performance and increased competition in the global market for lightweight components. Among all materials, composite materials have the potential to replace widely used steel and aluminum, and many times with better performance. Replacing steel components with composite components can save 60 to 80% in component weight, and 20 to 50% weight by replacing aluminum parts. Today, it appears that composites are the materials of choice for many engineering applications [2].

Reported the levels of composite shipments up to 545 million kg for transportation industries, and 340 million kg for construction industries in the USA for the year 2000. Also, composites have a great share in the high technology industries such as aerospace, defense, electronics, etc., up to shipment levels of 180 million kg [1].

1.2 Objective of the Study

The objective of this thesis is to assess the mechanical and physical properties of two different polymer composites reinforced by metal powders (Cu and Al) as follows:-

1- Mechanical properties:-

- Tensile test.
- Bending test.
- Impact test.
- Hardness test.

2- Physical properties:-

- Thermal conductivity.
- Morphology.

1.3 Organization of Thesis work

Chapter 2 of the thesis will cover the theory part of the composites; definitions, classifications, and focus on metals particles reinforced polymers like Al and Cu powders. Chapter 3 deals with the materials used and experimental work (preparation of mold, preparation of specimens, mechanical and physical testing procedure). Chapter 4 describes the experimental results. Chapter 5 discusses the experimental results which obtain from mechanical & physical test of prepared composites, and then compare the results of mechanical and physical properties of polymer (unsaturated polyester resin) composite reinforced with the aluminum powder and results obtained from copper powder polymer composite.

2.1 Introduction to Polymer

Polymers play a very important role in human life. Polymers are macromolecules built up by the linking together of large numbers of much smaller molecules. The small molecules that combine with each other to form polymer molecules are termed monomers. The small molecules that combine with each other to form polymer molecules are termed monomers and the reactions by which they combine are termed polymerizations. The unique properties of polymer are attributed to their long-chain structure. Physical properties are directly dependent on molecular weight and structure, The suffix in polymer 'mer' is originated from Greek word *mers* – which means part. The word polymer is thus coined to mean material consisting of many parts/mers [5-7].

Polymerization is a process of reacting monomer molecules together in a chemical reaction to form polymer chains or three-dimensional networks. There are many forms of polymerization and different systems exist to categorize them, The number of repeating units in the polymer is called the degree of polymerization [8]. Polymer can be classified in agreement with molecular structure to Fig. (1-2) [9]:

(a)-Linear polymers (b)- Branched polymers (c)-Cross linked polymers (d) -Network polymers

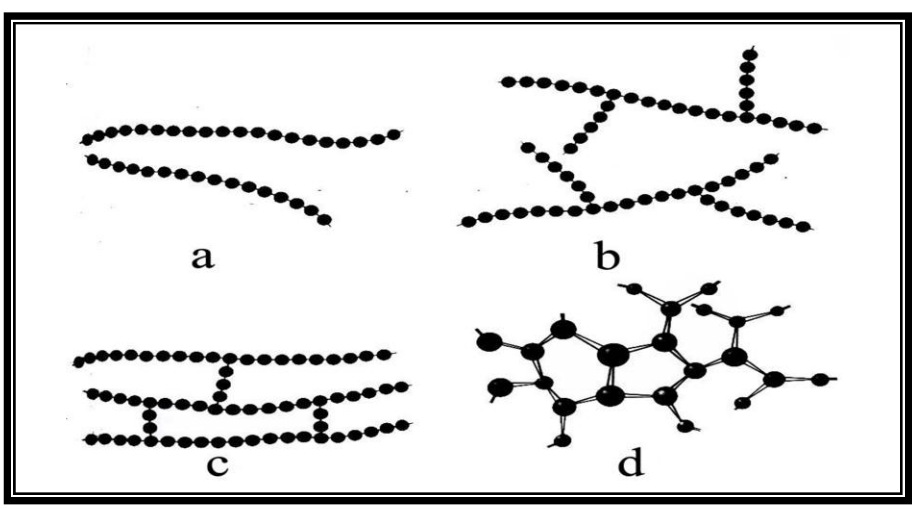


Fig. (2.1): Schematic representations of polymers: (a) Linear (b) Branched (c) Cross linked (d) Network [6]

Polymers are particularly attractive as matrix materials due to their relatively easy processability, low density and good mechanical and physical properties. They are divided into two broad categories: thermoplastics and thermosets.

2.1.1 Classification of Polymer Based on Thermal Behavior

In general, when exposed to heat, there are two classes of polymers based on their thermal behavior:

2.1.1.1 Thermosetting Polymers

The thermosetting polymers become permanently hard and rigid when heated or cured. These materials are generally used as liquid formulation, so they are cast into desired shape such as unsaturated polyester resin . Thermosetting polymers usually have a highly cross-linked or three dimensional network structures in which all atoms are connected by strong, covalent bonds. However, the crosslinks that form a rigid network of molecules cannot be broken, thus the polymer cannot be re-melted or reformed into another shape but decompose upon being heated to too high a temperature. Thus thermosets cannot be recycled, whereas thermoplasts can be recycled, typical thermosetting polymers are the polyesters, epoxies, and urethanes [10-13].

The most common thermoset resins employed in the composite manufacturing and their common characteristics are as follows [13, 14]:

- ❖ Unsaturated polyesters, with attractive mechanical, chemical and electrical properties accompanied with dimensional stability, cost and ease of processing and fast curing.
- ❖ Epoxies, with superior mechanical and electrical properties, resistance to corrosive environments, good performance at elevated temperatures.
- ❖ Vinyl esters, which combine the superior mechanical properties of epoxy resins with the handling advantages of the unsaturated polyester resins.
- ❖ Phenolics, with high performance characteristics like high temperature, chemical and creep resistance.
- ❖ Polyurethanes, with good impact resistance and
- ❖ Bismaleimides (BMI), with high temperature resistance.

2.1.1.2 Thermoplastic Polymer

This type of polymer consists of linear molecular chains without any cross-linking in structure, whereas the long molecular chains are bonded to each other by secondary bonding, i.e. Vander Weal's force. The thermoplastic polymers does not resist heat very well and so can be heat-softened melted and reshaped many times. When thermoplastic polymer is heated above glass transition temperature (Tg), it can be shaped and on cooling will be hard in this form, This type of polymer can be easily recycled because at each time it is reheated, it can again be reshaped or formed into a new shape such as PP, HDPE, and PC, this type of plastics have a good wide rang mechanical properties like high tensile strength, stiffness, compressive strength as well as impact resistance [11-13].

The most common thermoplastic resins employed in composite manufacturing and their common characteristics are as follows [1,13, 15]:

- Nylon, which has high toughness and impact resistance.
- Polyetheretherketone (PEEK), with excellent chemical and wear resistance.
- Polypropylene (PP), with high specific strength, low cost, very good chemical resistance and ductility.
- Polyphenylene sulphide (PPS), with excellent balance in strength and high temperature resistance at low cost.
- Polyimides (PAI), that have relatively high service temperature range.
- Traditionally, thermoset polymers are employed in fiber reinforced composites. They are an important source of properties, superior mechanical characteristics, and better handling properties compared to thermoplastic resin systems.

2.2 Composite materials

Composite materials are those that are formed by the combination of two or more materials to achieve properties that are superior to those of its constituents [16, 17]. Composites consist of one or more discontinuous phases embedded in a continuous phase called the reinforcement or reinforcing material, whereas the continuous phases is termed the matrix [18]. Composites are used because overall properties of the composites are superior to those of the individual components for example polymer and ceramic. Composites have a greater modulus than the polymer component but aren't as brittle as ceramics [1,3,15]. A composite material generally depends on three elements [19, 20].

1. Matrix.
2. Reinforcement material.
3. Interface and bonding.

2.2.1 Matrix

The main definition of Matrix is the continuous phase in a composite material which gives several advantage to the composite. The first to bind the reinforcement phase, play important act to transfer the stress between fillers, and protects the reinforcement from an environment conditions [21]. It can be classified as a composite material based on the matrix type: metal matrix composites (MMCs), ceramic matrix composites (CMCs) and polymer matrix composites (PMCs) [3,22].

2.2.1.1 Metal Matrix Composites (MMCs)

The MMCs are materials consisting of metal alloys reinforced with continuous fibers, particulates or whiskers. The addition of these reinforcements give MMCs superior mechanical properties and unique physical characteristics. The two most commonly used metal matrices are based on Aluminum and Titanium which both have comparatively low specific gravities. Also, Beryllium, Magnesium, Nickel and Cobalt based super alloys can be used as matrix materials regarding the needs and service conditions of the application [3,22].

2.2.1.2 Ceramic Matrix Composites (CMCs)

Ceramic Matrix Composite (CMC) is a material consisting of a ceramic matrix combined with a ceramic (oxides, carbides), continuous fibers, whiskers, or particulates which are (dispersed phase), Short-fiber (discontinuous) composites are produced from an oxide (alumina) or non-oxide (silicon carbide), ceramic matrix reinforced by whiskers of silicon carbide (SiC), titanium boride (TiB_2), zirconium oxide (ZrO_2) and other ceramic fibers, Ceramics have very attractive properties for many applications; high strength and stiffness at high temperatures and chemical resistance. But the one serious disadvantage of this class of material is that their susceptibility to impact damage. CMCs used for application at temperature no more than 1500 ºC [3,15].

2.2.1.3 Polymer Matrix Composites (PMCs)

Polymer Matrix Composite (PMC) is the material consisting of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase. Polymer Matrix Composites are very popular due to their low cost and the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipments required for manufacturing polymer matrix composites are simpler. For this reasons polymer matrix composites developed rapidly and soon became popular for structural applications. In polymer matrix composites, as in all composite materials, the matrix serves to transfer stresses between the fibers, holds the reinforcement phase in place and protects the surface of the fibers from mechanical abrasion and environmental condition . It has a minor role in tensile load carrying capacity of the composite structure [13,23]. The advantages of polymer composites are:

1. High tensile strength
2. High stiffness
3. High Fracture Toughness
4. Good abrasion resistance
5. Good puncture resistance
6. Good corrosion resistance
7. Low cost
8. The ability to fabricate directional mechanical properties
9. Excellent fatigue and fracture resistance
10. Lower tooling cost alternatives
11. Lower thermal expansion properties
12. Simplification of manufacturing by parts integration

The main disadvantage of Polymer Matrix Composites (PMC) is Low thermal resistance Two types of polymers are used as matrix materials for fabrication composites: Thermosets (epoxies, unsaturated polyester) and Thermoplastics ((LDPE), (HDPE), PP, nylon, acrylics).

The mechanical properties of polymeric resin systems employed as matrix materials are given in Table 2.1.

Table 2.1 Mechanical properties of resins [24]

Resin Type	Density (Mg/m3)	Modulus (GPa)	Strength (MPa)
THERMOPLASTIC			
PEEK	1.26 – 1.32	3.2	93
PP	0.9	1.1 – 1.6	31 – 42
PPS	1.36	3.3	84
PAI	1.4	3.7 – 4.8	93 – 147
THERMOSET			
Polyester	1.1 – 1.23	3.1 – 4.6	50 – 75
Epoxy	1.1 – 1.2	2.6 – 3.8	60 – 85
Vinyl Ester	1.12 – 1.13	3.1 – 3.3	60 – 90
Phenolic	1.0 – 1.25	3.0 – 4.0	60 – 80
Polyurethan	1.2	0.7	30 – 40
Bismaleimides	1.2 – 1.32	3.2 – 5.0	48 – 110

2.2.2 Reinforcement materials

The composites may be classified according to their reinforcement types:

• Fiber reinforced composite

• Particle reinforced composite

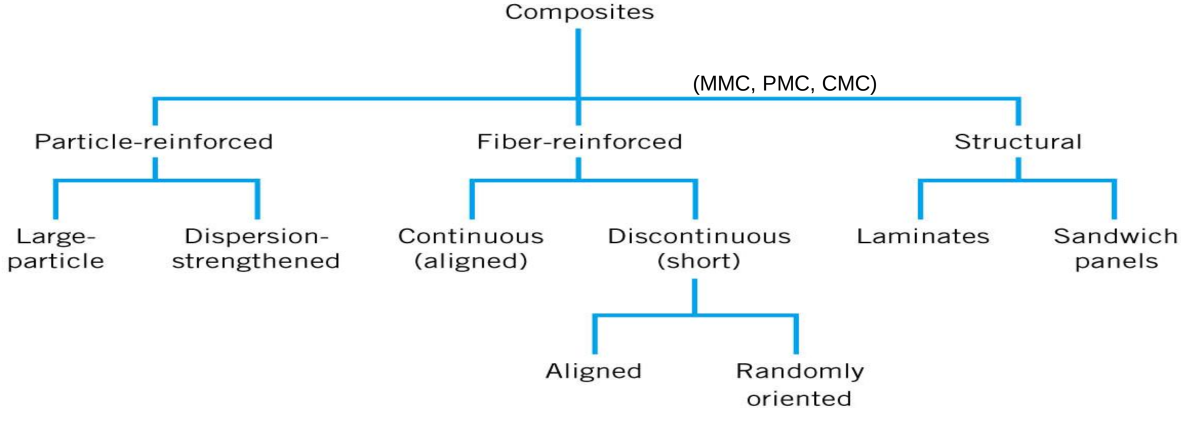


Fig. (2.2) classification of composite materials [25].

2.2.2.1 Fiber reinforced composite

Reinforcement need not necessarily be in the form of long fibers. One can have them in the form of particle, flakes, whiskers, short fiber, continuous fibers, or sheets. It turn out that most reinforcements used in composites have a fibrous form because materials are stronger and stiffer in the fibrous form than any other form. Specifically, in this category, Fibers are the reinforcement and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and/or reduce the product cost. Common fiber reinforcing agents include asbestos, carbon and graphite fibers, beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminum oxide, glass fibers, polyamide, natural fibers etc. [15,16].

2.2.2.2 Particle reinforced composite

Particles are used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as Aluminum and Copper. Particles are used to improve the mechanical properties such as wear resistance and increase the modules of the matrix and to decrease the ductility of the matrix. Particles are also used to reduce the cost of the composites. Reinforcements and matrices can be common, inexpensive materials and are easily processed. Some of the useful properties of ceramics and glasses include high melting temp., low density, high strength, stiffness; wear resistance, and corrosion resistance. Many ceramics are good electrical and thermal insulators. Ceramics and glasses have one major drawback: they are brittle. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes. Mechanical properties of the composites have greatly been affected by the shape, size, volume fraction, and specific surface area of such added particles [26, 27].

2.2.2.2.1 Particle size

Enhancement in the mechanical properties are directly related to filler particle size. Currently, particle size is being reduced rapidly and many studies have focused on how single-particle size affects mechanical properties, particle size of filler have significant effects on the mechanical properties such as fatigue resistance, modulus, tensile and fracture, Smaller particulate fillers impart greater reinforcement to the polymer compound than the coarse ones Since particle size is directly related to the surface area of filler, increasing of surface area that is in contact with polymer phase which probably leads to the increase in reinforcement. Reducing particle size also simply results in a greater influence of polymer-filler interaction. Reinforcement is the presence of large particles or agglomerates in the polymer. These agglomerates not only reduce the contact between filler and matrix but function as failure initiation sites which would lead to premature failure of materials [3].

2.2.3 Interface and bonding

The interface between a reinforcement and a matrix can be define as the bonding surface between the two across which a discontinuity in some parameter occurs. The discontinuity across the interface may be sharp or gradual. In any event, an interface is the region through which material parameters, such as concentration of an element, crystal structure, density, elastic modulus, coefficient of thermal expansion, etc., change from one side to another. Clearly, given interface may involve one or of these items. The interface plays an important role in the performance of a composite. The reinforcement strengths the matrix only if strong interfacial bond exists between them, In most polymeric matrix composites, increase in interfacial bond strength is achieved by filler surface treatment, which helps in forming chemical linkage between the filler and the matrix across the interface, Generally, a mechanical bond is formed due to differential shrinkage as the polymer matrix cools down from the processing temperature [28-30].

In general parameters affecting the properties of polymer composites, whether continuous or discontinuous, include:

1. The properties of the additives (inherent properties, size and shape).
2. Composition.
3. The interaction of component at the phase boundaries, which is also associated with the existence of a thick interface, known also as the interface, this is often considered as a separate phase, controlling adhesion between the component.
4. The method of fabrication.

The present work has been taken up to develop a series of unsaturated polyester resin based composites with aluminum and copper powder reinforcement and to study the comparative in the mechanical and physical properties of these composite.

3.1 Introduction

In this chapter, a detailed description of the experimental methodology is presented, which include, materials selection, sample preparation methods and detailed description of test instruments used. The figures (3.1,3.2) show the experimental work that was carried out:

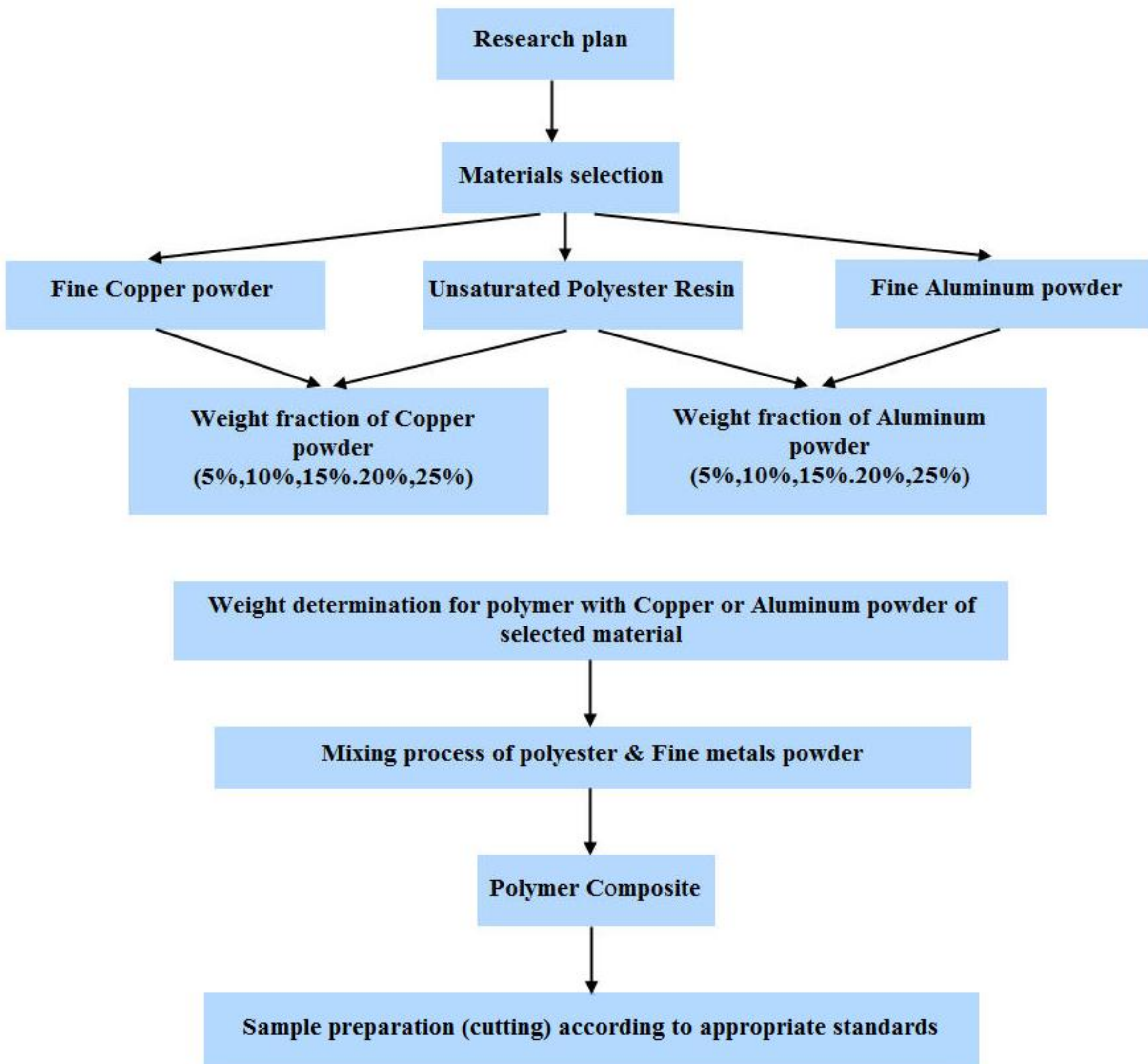


Fig. (3.1) The chart of steps for the present research

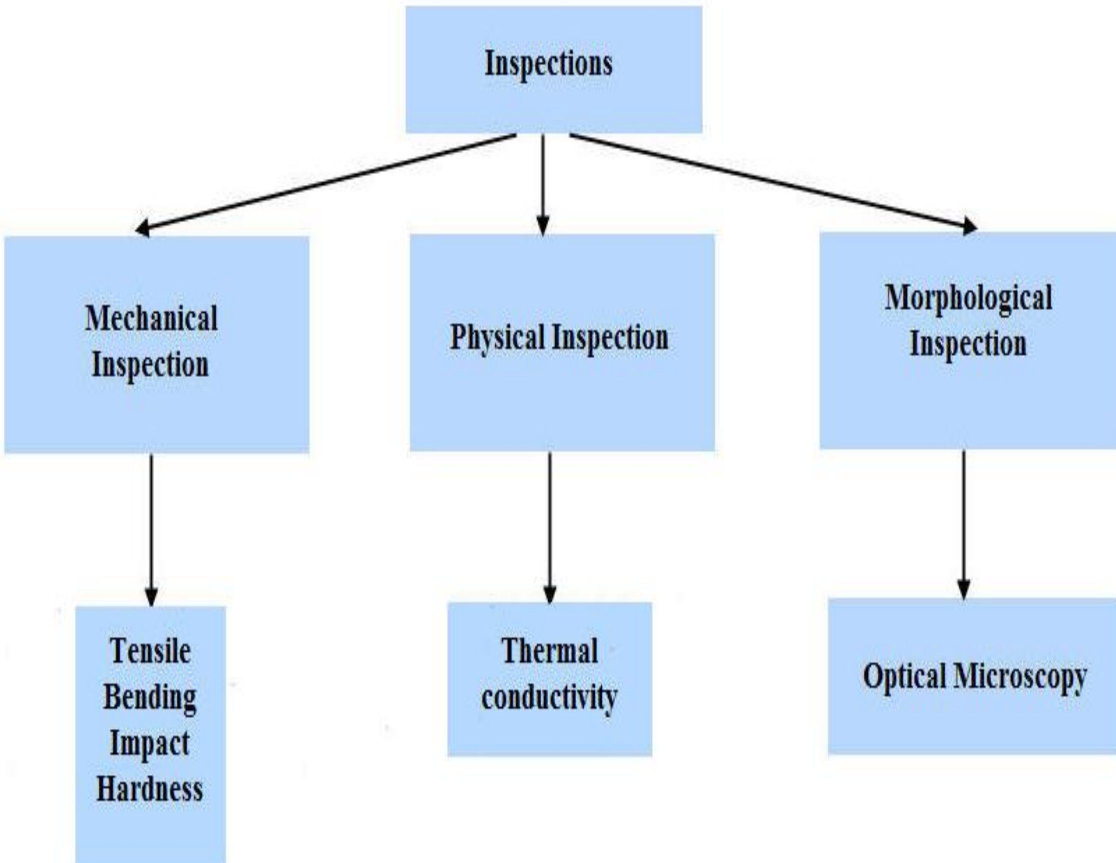


Fig. (3.2) The chart of steps for the inspections of present research

3.2 The used material

In this research, one type of polymer material was used, (unsaturated polyester resin, provided from Gulf Chemicals and Industrial Oils Company, Saudi Arabia, copper powder and aluminum powder.

3.2.1 Unsaturated polyester resin(UPR)

Unsaturated polyester resin used in this study was produced from Gulf Chemicals and Industrial Oils Company, Saudi Arabia. This type has density 1.12g/cm^3 and max work temperature 170 ºC.

3.2.2 Copper powder

Polymer composite were reinforced by Copper metal powder particles with median particle size (15.598µm), for the particle size analysis the instrument used was a laser diffraction particle size analyzer type (SHIMADZU SALD 2101). The particle size analysis was done as shown in Fig. (3.3). The copper micro particles were used in this study (Himidia Company, India), The Atomic weight At.Wt (63.55), Minimum Assay (99.7), and Maximum limits of impurities as follows.

Iron (Fe) = 0.005% .

Lead (pb) = 0.01% .

Arsenic (As) = 0.0001% .

Manganese (Mn) = 0.001% .

Figs. (3.4,3.5) show localized chemical analysis and standard of Cu powder by EDX .

3.2.3 Aluminum powder

Polymer composite were reinforced by Al metal powder electrolytic particles with median particle size (11.533µm), for the particle size analysis the instrument used was a laser diffraction particle size analyzer type (SHIMADZU SALD 2101), the particle size analysis was done as shown in Fig. (3.6). Al micro particles used in this study (Angang Group Aluminum Powder Co., Ltd, china).

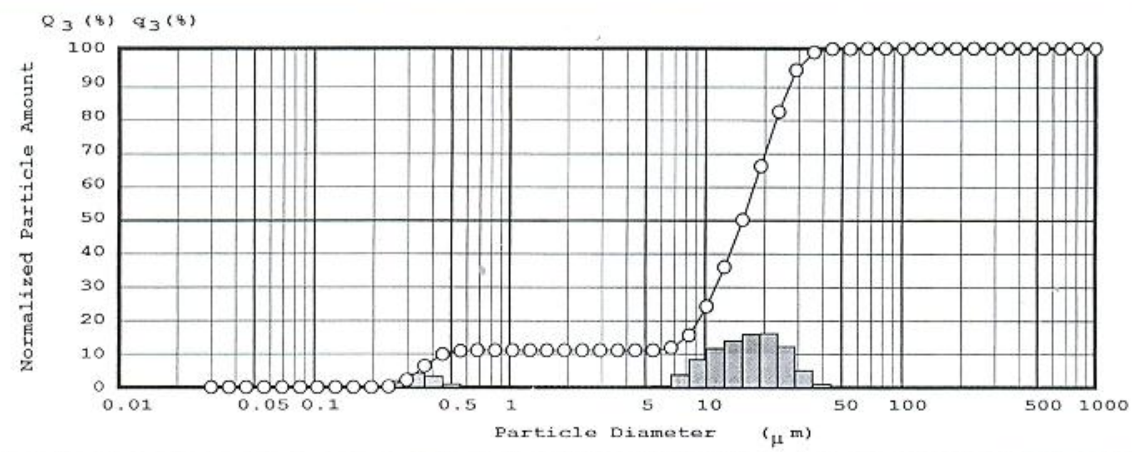
Purity: 99.75%-99.995% 3. Fe<0.08%, Si<0.08% 4. Water<0.02%

Figs. (3.7,3.8) show localized chemical analysis and standard of Al powder by EDX.

SHIMADZU SALD-2101 (SALD-2101-WEA1:V1.20)

(File Name)
(Sample ID) Cu (Sample #)
(Date) 04/01/01 (Time) 00:06:49

R Index=1.60-0.10i	Median D : 15.598	Mean V : 10.728	10.0%D : 0.459	S Level : 0
	Modal D : 21.210	Std Dev : 0.551	50.0%D : 15.598	D Func :None
			75.0%D : 21.643	D Shift : 0



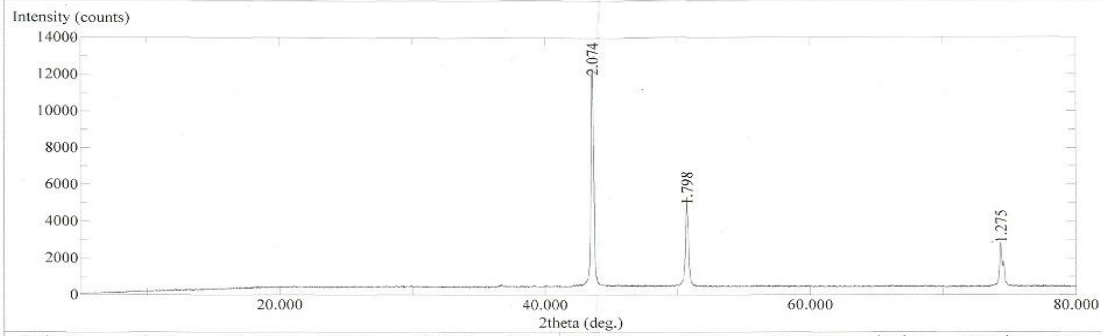
	Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)		Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)		Diam x(μ m)	Cum Q_3(%)	Diff q_3(%)
1	1000.000	100.000	0.000	18	28.988	93.763	12.298	35	0.840	11.029	0.002
2	811.975	100.000	0.000	19	23.538	81.466	16.049	36	0.682	11.027	0.090
3	659.303	100.000	0.000	20	19.112	65.417	15.805	37	0.554	10.938	1.036
4	535.337	100.000	0.000	21	15.518	49.611	14.003	38	0.450	9.901	3.395
5	434.680	100.000	0.000	22	12.601	35.608	11.632	39	0.365	6.506	4.205
6	352.949	100.000	0.000	23	10.231	23.977	8.419	40	0.297	2.301	1.946
7	286.586	100.000	0.000	24	8.308	15.557	3.708	41	0.241	0.355	0.333
8	232.700	100.000	0.000	25	6.746	11.849	0.763	42	0.196	0.022	0.021
9	188.947	100.000	0.000	26	5.477	11.086	0.056	43	0.159	0.000	0.000
10	153.420	100.000	0.000	27	4.447	11.030	0.001	44	0.129	0.000	0.000
11	124.573	100.000	0.000	28	3.611	11.029	0.000	45	0.105	0.000	0.000
12	101.150	100.000	0.000	29	2.932	11.029	0.000	46	0.085	0.000	0.000
13	82.131	100.000	0.000	30	2.381	11.029	0.000	47	0.069	0.000	0.000
14	66.689	100.000	0.001	31	1.933	11.029	0.000	48	0.056	0.000	0.000
15	54.149	99.999	0.069	32	1.570	11.029	0.000	49	0.046	0.000	0.000
16	43.968	99.929	0.986	33	1.275	11.029	0.000	50	0.037	0.000	0.000
17	35.701	98.944	5.180	34	1.035	11.029	0.000	51	0.030	0.000	0.000

Sampling Mode : Manual Refractive Index : 1.60-0.10i
Signal Accumulation Count : 1 Interval (sec) : ___ Signal Averaging Count : 64
Max of Absorbance Range : 0.200 Min of Absorbance Range : 0.010
Ultrasonic Dispersion Time (sec) : ___ Waiting Time After Ultrasonic Dispersion(sec) : ___

Fig.(3.3) Particle size analysis of Copper powder.

Peak Search

Sample : TESTSAMPLE File : 1495CU.raw Date : May-31-12 13:54:57 Operator : Administrator
Comment : Memo :
Method : 2nd differential Typical width : 0.500 deg. Min. height : 240.00 counts



Peak no.	2theta	Flex Width	d-value	Intensity	I/Io
1	43.600	0.306	2.0742	11968	100
2	50.740	0.329	1.7978	4890	41
3	74.360	0.306	1.2746	2786	24

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Fig.(3.4) Localized chemical analysis of copper powder by EDX.

Copper, syn

Ref: Swanson, Tatge, Natl. Bur. Stand. (U.S.), Circ. 539, I, 15 (1953)

d(A)	Int.	h	k	l
2.088	100	1	1	1
1.808	46	2	0	0
1.278	20	2	2	0
1.090	17	3	1	1
1.0436	5	2	2	2
.9038	3	4	0	0
.8293	9	3	3	1
.8083	8	4	2	0

Ref: Ibid.

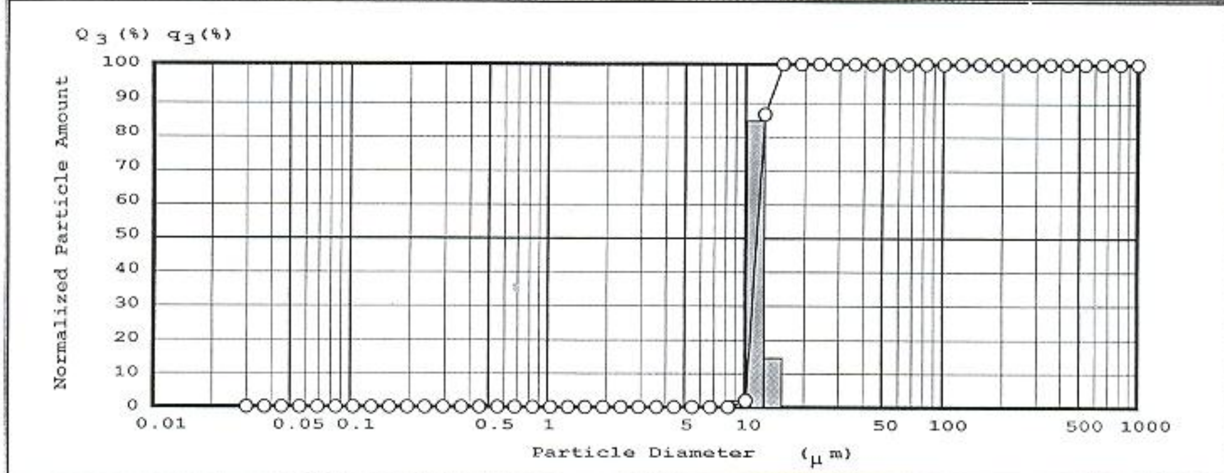
Color: Red
Pattern taken at 26 C. Sample from metallurgical laboratory of NBS, Gaithersburg, MD, USA. CAS #: 7440-50-8. It had been heated in an H2 atmosphere at 300 C. Impurities from 0.001-0.01% Ag, Al, Bi, Fe, Si, Zn. Opaque mineral optical data on specimen from unspecified locality, R3R%=60.65, Disp.=Std., VHN100=96-104, Ref.: IMA Commission on Ore Microscopy QDF. Measured density and color from Dana's System of Mineralogy, 7th Ed., I 99. Cu type. Gold group, gold subgroup. PSC: cF4. Mwt: 63.55. Volume[CD]: 47.24.

Fig.(3.5) The standard localized chemical analysis for copper powder by EDX.

SHIMADZU SALD-2101 (SALD-2101-WEA1:V1.20)

(File Name)
(Sample ID) Al (Sample #)
(Date) 04/01/01 (Time) 00:16:06

R Index=1.60-0.10i	Median D : 11.533	Mean V : 11.610	10.0%D : 10.439	S Level : 0
	Modal D : 11.354	Std Dev : 0.036	50.0%D : 11.533	D Func :None
			75.0%D : 12.275	D Shift : 0



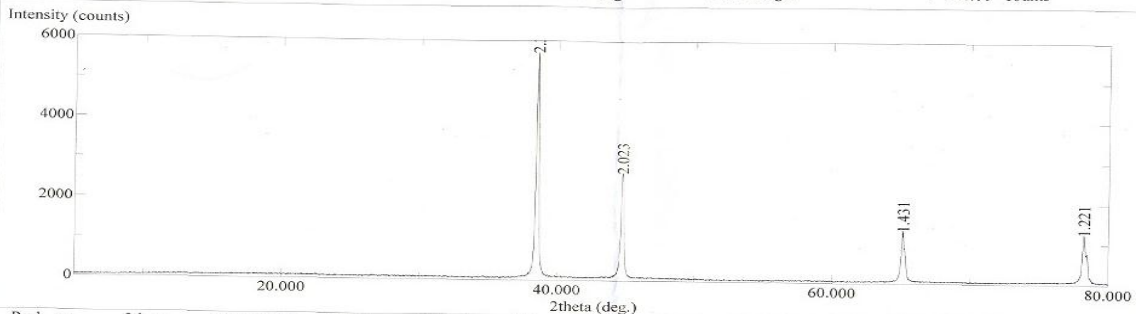
	Diam x(μ m)	Cum Q_3 (%)	Diff q_3 (%)		Diam x(μ m)	Cum Q_3 (%)	Diff q_3 (%)		Diam x(μ m)	Cum Q_3 (%)	Diff q_3 (%)
1	1000.000	100.000	0.000	18	28.988	100.000	0.000	35	0.840	0.000	0.000
2	811.975	100.000	0.000	19	23.538	100.000	0.000	36	0.682	0.000	0.000
3	659.303	100.000	0.000	20	19.112	100.000	0.000	37	0.554	0.000	0.000
4	535.337	100.000	0.000	21	15.518	100.000	14.495	38	0.450	0.000	0.000
5	434.680	100.000	0.000	22	12.601	85.505	83.558	39	0.365	0.000	0.000
6	352.949	100.000	0.000	23	10.231	1.947	1.947	40	0.297	0.000	0.000
7	286.586	100.000	0.000	24	8.308	0.000	0.000	41	0.241	0.000	0.000
8	232.700	100.000	0.000	25	6.746	0.000	0.000	42	0.196	0.000	0.000
9	188.947	100.000	0.000	26	5.477	0.000	0.000	43	0.159	0.000	0.000
10	153.420	100.000	0.000	27	4.447	0.000	0.000	44	0.129	0.000	0.000
11	124.573	100.000	0.000	28	3.611	0.000	0.000	45	0.105	0.000	0.000
12	101.150	100.000	0.000	29	2.932	0.000	0.000	46	0.085	0.000	0.000
13	82.131	100.000	0.000	30	2.381	0.000	0.000	47	0.069	0.000	0.000
14	66.689	100.000	0.000	31	1.933	0.000	0.000	48	0.056	0.000	0.000
15	54.149	100.000	0.000	32	1.570	0.000	0.000	49	0.046	0.000	0.000
16	43.968	100.000	0.000	33	1.275	0.000	0.000	50	0.037	0.000	0.000
17	35.701	100.000	0.000	34	1.035	0.000	0.000	51	0.030	0.000	0.000

Sampling Mode : Manual Refractive Index : 1.60-0.10i
Signal Accumulation Count : 1 Interval (sec) : ___ Signal Averaging Count : 64
Max of Absorbance Range : 0.200 Min of Absorbance Range : 0.010
Ultrasonic Dispersion Time (sec) : ___ Waiting Time After Ultrasonic Dispersion(sec) : ___

Fig.(3.6) Particle size analysis of Aluminum powder.

Peak Search

Sample : TESTSAMPLE — File : 1495AL2.raw — Date : May-31-12 13:18:32 — Operator : Administrator
Comment : — Memo :
Method : 2nd differential — Typical width : 0.500 deg. — Min. height : 100.00 counts



Peak no.	2theta	Flex Width	d-value	Intensity	I/Io
1	38.500	0.306	2.3364	5689	100
2	44.760	0.306	2.0231	2687	48
3	65.140	0.353	1.4309	1293	23
4	78.240	0.329	1.2208	1228	22

May-31-2012 13:54:17 Page-1

Fig.(3.7) Localized chemical analysis for Al powder by EDX.

Aluminum, syn [NR]

Ref: Swanson, Tatge, Natl. Bur. Stand. (U.S.), Circ. 539, I, 11 (1953)

Ref: Ibid.

Color: Light gray metallic
Pattern taken at 25 C. CAS #: 7429-90-5. The material used for the NBS sample was a melting point standard sample of aluminum prepared at NBS, Gaithersburg, MD, USA. The chemical analysis (%): Si 0.011, Cu 0.006, Fe 0.007, Ti 0.0001, Zr 0.003, Ga 0.004, Mo 0.00002, S 0.0001, Al 99.9+ (by difference). Mineral species of doubtful validity, Am. Mineral., 65 205 (1980). Cu type. Gold group, gold subgroup. PSC: cF4. Mwt: 26.98. Volume[CD]: 66.40.

d(A)	Int	h	k	l
2.338	100	1	1	1
2.024	47	2	0	0
1.431	22	2	2	0
1.221	24	3	1	1
1.169	7	2	2	2
1.0124	2	4	0	0
.9289	8	3	3	1
.9055	8	4	2	0
.8266	8	4	2	2

Fig.(3.8) The standard localized chemical analysis of Al powder by EDX.

3.3 Preparing of polymer composites

3.3.1 Steps of preparation of mold

1) The first step was preparing of glass mold which have the dimension of the same dimensions of preparation polymer composite, before the pouring of mixture in the mold, the method of preparing the mold as follows :

A- Cutting the glass base which have the dimensions of (35 cm*35cm*5mm)

B- Cutting four pieces to forming the frame of the mold, two pieces have dimensions (25cm*3cm*5mm) and the other two pieces have dimensions (18cm*3cm*5mm) in order to get a suitable thickness for inspections.

2) Using of thermal plastic papers (laminate layers) to prevent the adhesion of polyester on the glass, because of the laminate layers is smooth and resist the temperature of mixture which have exothermic reaction.

3) Putting of one laminate layer on the glass base to prevent the adhesion of mixture on the glass mold because the polymer has adhesion property.

4) Forming of the frame by adhesion the four pieces in (B) by using the thermal silicon adhesive to making the rectangular frame as a location of specimen.

3.3.2 Steps of preparation of the specimens

1) Putting the glass mold on the balancing table, check the balance of the table by scale to confirm that the table will be have the same level in every point of the table, also take balancing of the glass mold by the scale, otherwise, sometime the level of the liquid surface mixture after pouring in the glass mold will not be equal because of high viscosity flow of liquid mixture.

2) Weighting the suitable weight of unsaturated polyester resin which is required from previous selected ratio depending of weight fraction are put it in glass container.

3) Weighting the suitable weight of metal powder, which is required from previous calculation depending of weight fraction and, then putting it in glass container for mixing with the polyester resin.

4) Mixing the suitable amount of polyester resin and metals powder which are shown in (2&3) steps which mentioned above by using of hand mixing or ultrasonic mixing device for this purpose.

5) Starting the mixing by using wood straws and move them by hand, continue at least half an hour to insurance riddance of porous which are generated in the first mixing between the polyester resin and metals powders, the porous in the first time exists along the resin because in beginning the particles of metals powder will diffuse in the polymer caused mini air bubbles and also the interface spaces between particles will generate porous which accumulate together making bubbles rise on the surface of mixture, after a long time of mixing the porous will rising on the surface of mixture, therefore it is very necessary to insure that:

- ❖ The surface and the mixture have not any porous and cavities.
- ❖ There are not any accumulations of particles in the bottom of the container because the density of metal particles is more than polymer.
- ❖ The mixture become homogenous seeming like light liquid, after that going to next step.

6) If the weighting percentage of hardener added exceeds 1% it will increase the problems in mixing like smoothness of the surface, getting pores and cavities on the surface due to polymer will solidify rapidly cause shrinkage and make cracks on the surface. The specimen should be free from pores for getting right result of mechanical and physical tests. To getting a good homogenous between hardener and polyester resin the time of mixing should be at least 10 minute to insure that the hardener diffuse homogenously along the polymer otherwise the defects will be appear like :

- ❖ Crack due to the nonhomogeneous distribution of hardener in the polymer so some regions will solidify before another regions.
- ❖ Gaps and cavities because of the same reason in previous point and mistake in pouring method & accumulate of particles of metal powder in some regions which be rich in

metal powder and poor in polymer, another regions will poor in metal powder and rich in polymer.

7) Covering the upper surface of the specimen by laminate layer immediately after pouring the mixture in the mold to getting a smooth surface and prevent the forming of porous after curing of resin, because the laminate layer it will be prevent the shrinkage of polyester resin on the surface of the specimen, this shrinkage will make porous on the surface, also to prevent the oxygen which touch the surface of the specimen and it will be make some regions of the surface solidify rapid than another regions and leave porous in the regions which not solidify.

8) Putting of suitable piece of glass plate above the upper laminate layer after a few minutes on the surface prevents the shrinkage of polyester resin. The mixing resin with hardener is a exothermic reaction, so if glass plate of suitable weight is not put on the specimen, it will shrink and bend completely because of heating effects, and that make it difficult to get the suitable specimens for tests.

3.4 Cutting

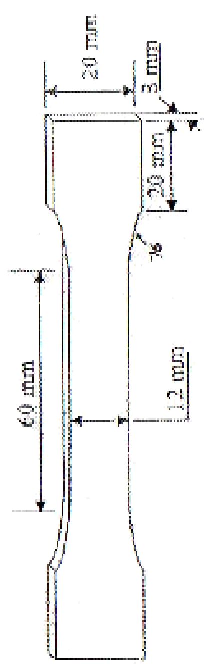
After preparing the plates with previous dimensions were produced and have been prepared for cutting and mechanical machining by using saw with very soft teeth to ensure that samples would not fracture through cutting because the plates are rigid and brittle so if the cutting processing is done quickly the specimen will break and deformed through processing, cutting was done according to international standard specifications for each test used. Table (3.1) shows the international standard specifications for the samples and the used instrument in the inspections.

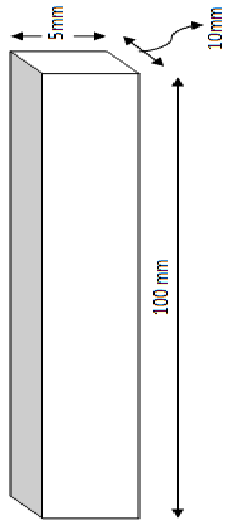
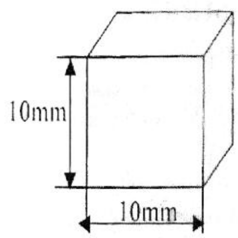
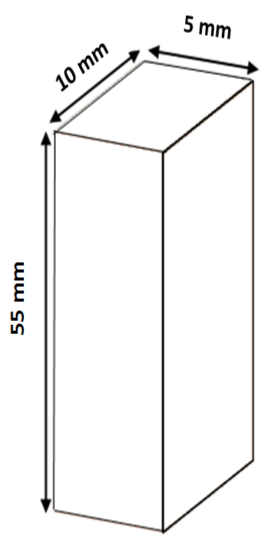
3.5 Inspections

3.5.1 Tensile Test

Samples were cut according to ASTM D638 type 1 specimen dimensions as shown in Table (3.1). The machine used for the testing of tensile properties is micro computer controlled electronic universal Testing Machine (model WDW 50 E). The test was conducted at velocity (2 mm/min) at ambient temperature, tensile stress was applied till the failure of the sample and stress-strain curve was obtained. Each sample was tested 2 times and average results have been reported. Table (3.2) shows images of the samples before the test.

Table (3.1) The standard specifications for test specimens.

Test Type	Specification	Sample	Pictures of the machines
Tensile Test	ASTM –D638		

Bending Test	ASTM-D790		
Hardness Test (Shore D)	ASTM-D570		
Impact Test	ISO-179		

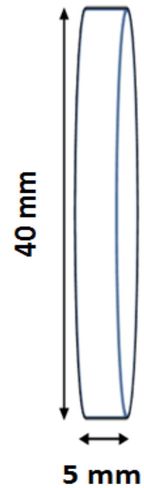
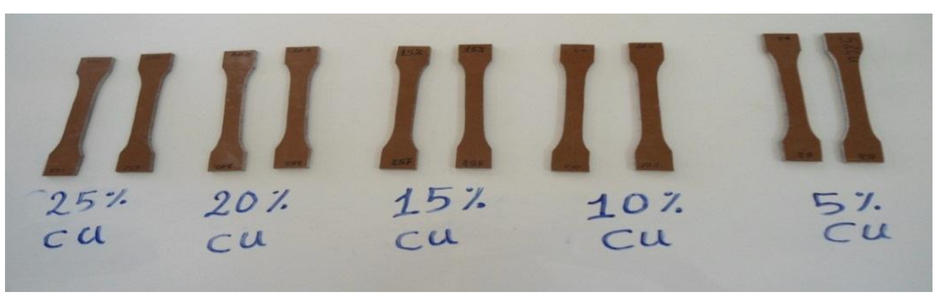
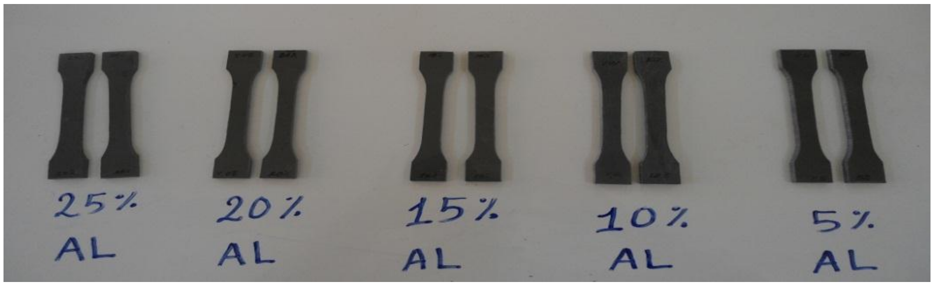
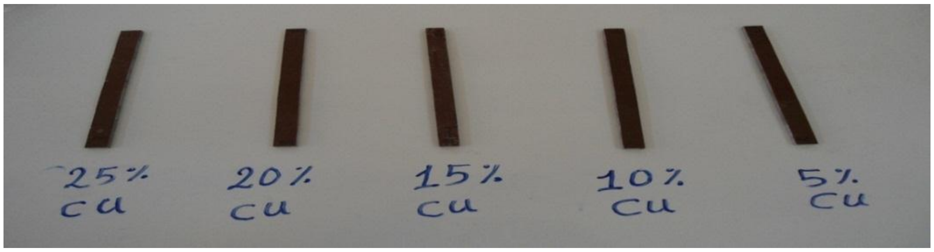
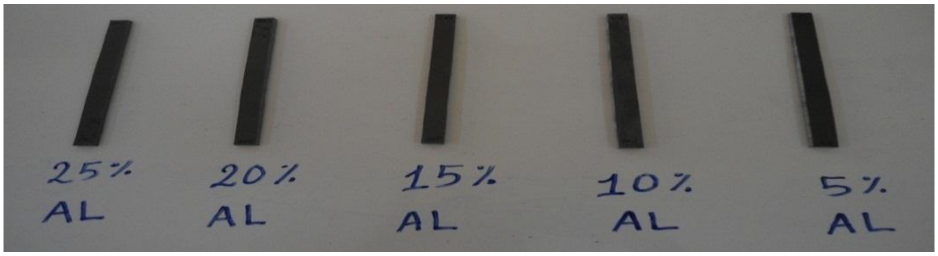
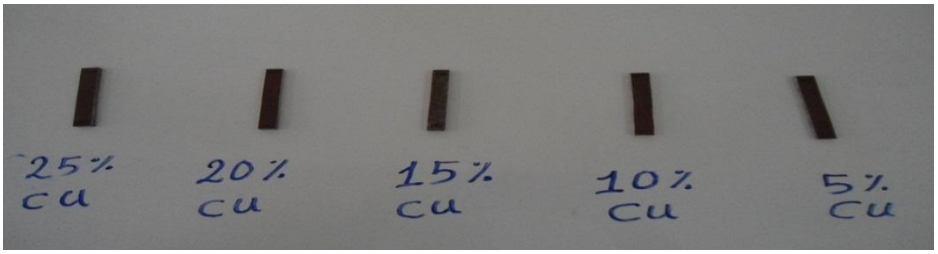
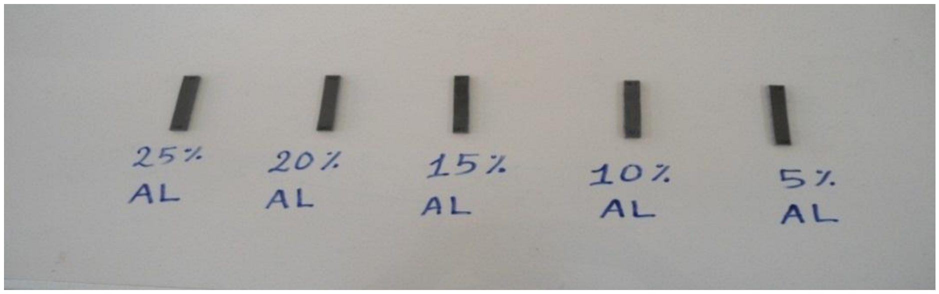
Thermal Conductivity Test	According to specification of instrument		
Morphology Test			

Table (3.2) Shows images of original samples for polymer metals composites that prepared in this research.

Type of the test	Images before the test
Tensile test	 Images of tensile specimens of polyester Cu powder composites.

	 Images of tensile specimens of polyester Al powder composites
Bending Test	 Images of Bending specimens of polyester Cu powder composites.  Images of Bending specimens of polyester Al powder composites.
Impact Test	 Images of Impact specimens of polyester Cu powder composites.

<table>
<tr>
<td></td>
<td>

Images of Impact specimens of polyester Al powder composites.</td>
</tr>
<tr>
<td>Thermal Conductivity Test</td>
<td>
25% 20% 15% 10% 5%
Images of Thermal Conductivity specimens of polyester Cu powder composites.

25% 20% 15% 10% 5%
Images of Thermal Conductivity specimens of polyester Al powder composites.</td>
</tr>
</table>

3.5.2 Bending Test

For the study, bending behavior of the prepared samples were cut according to ASTM-D790 specimen dimensions as shown in Table (3.1). The machine used for the testing of tensile and bending properties is micro computer controlled electronic universal Testing Machine (model WDW 50 E). The test was conducted at velocity (0.5 mm/min) at ambient temperature, bending stress was applied till the failure of the sample and stress-strain curve was obtained. Each sample was tested 2 times and average results have been reported. Table (3.2) shows images of the samples before the test.

3.5.3 Impact Test

It is considered one of the most important mechanical tests that gives the absorption of energy that is required for fracture of the sample which is given directly from the device, furthermore Impact strength G_c and fracture toughness K_c can be calculated through the relationships (3.1) and (3.2) respectively. The impact test instrument model XJU-22, supplied from Time group Inc. was used. Samples with dimensions (55×10×4) were used as shown in Table (3.1) without notched point. Using Izod method the sample was placed vertically, the testing method of this instrument includes lifting of pendulum to its maximums height and fixing it firmly where its potential energy would be changed to kinetic energy.

From this test, the following can be obtained :

Impact strength can be calculated from the following relationship:-

$$G_c = U_c / A \tag{3.1}$$

Where:

G_c : The impact strength of the material (J/m^2).

U_c: The required energy for sample fracture (J).

A : The cross sectional area of the sample (m^2).

Fracture toughness can be calculated as follows:

$$K_c = \sqrt{G_c \times E_b} \quad (3.\ 2)$$

K_c: Fracture toughness of the sample (N/mm^2).

G_c: Impact strength of the material (J/m^2).

E_b: Young Modulus of the material (MPa).

3.5.4 Hardness Test

It has been used D types of shore to measure the hardness of the samples, and the used ones must have smooth, plain surface with thickness at least more than (3mm) and must not be exposed to mechanical vibrations so the prepared sample has (10×10×4) mm. These dimensions were taken according to ASTM-570 as shown in Table (3.1). Shore instrument is similar to compass containing needle subjected perpendicular on the sample and waiting some seconds to read the value and to have some accuracy an average of five readings have to be taken in different points for each sample.

3.5.5 Thermal Conductivity Test

For the measurement of thermal conductivity, the apparatus used was a modification of the standard Lee's disk instrument (Griffen and George Company/ England). A diagram of the apparatus is shown in figure (3.9). This consists of three copper plates (A, B and C) and a 6W electrical plate heater of the same diameter as the copper plates. The sample to be studied was cut to the same diameter as the copper plates (40) mm and to a thickness of approximately (5) mm. A value for the thermal conductivity of the specimen (K) of thickness d and radius r was calculated from the following [25]:

$$K= [ed/2\pi r^2(T_B-T_A)]\times[a_s(T_A+T_B)/2+2a_AT_A] \quad (3.3)$$

Where e is given by:

$$E =VI/[a_AT_A+a_s(T_A+T_B)/2+a_H(T_B+T_C)/2+a_B T_B + a_C T_C] \quad (3.4)$$

a_A,a_B,a_C a_S and a_H are the exposed surface areas of A, B, C and the specimen and heater respectively. Areas a_A and a_C include the flat ends of the discs. T_A, T_B and T_C are the temperatures of the discs A, B and C above ambient. (V) is the potential difference a cross the heater and (I) is the current which flows through it. K = Thermal conductivity in (w / m ˚C). Table (3.2) shows images of the samples before the test.

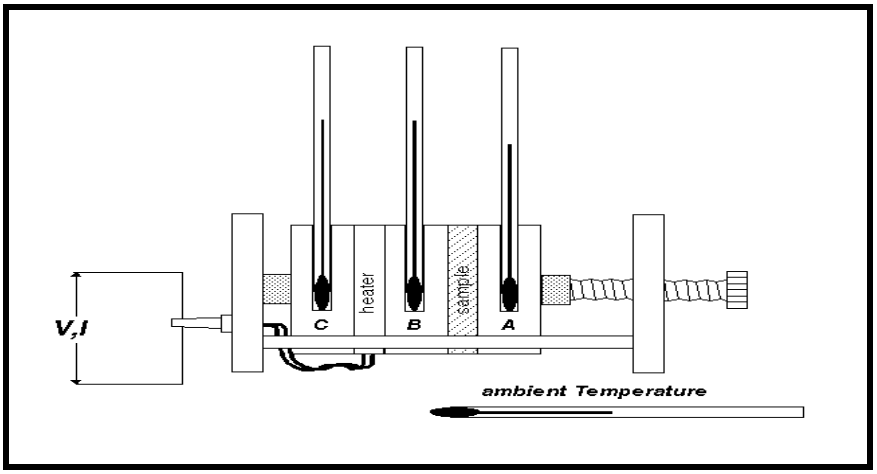


Fig. (3.9) Lees' Disk Apparatus (schematic).

3.5.6 Morphological Test

Optical Microscope (OM) (model MA-100, NIKON company , Japan) was used to examine the morphology of both polymer composites reinforced by Cu and Al powder, Table(3.1) shows image of optical microscope instrument.

4.1Introduction

This chapter includes all the experimental results that are obtained from the mechanical and physical for the polymer composite reinforced by copper particles as a first groups and polymer composite reinforced by aluminum particles as a second groups under investigation. The mechanical properties include (Tensile, Bending, Impact, and Hardness tests), the physical properties include Thermal Conductivity and morphology.

In this chapter, the results of all ratios that have been selected for unsaturated polyester resin and their composites are presented.

1- Unsaturated polyester resin: Cu particles (100:0, 95:5, 90:10, 85:15, 80:20 and 75:25).
2- Unsaturated polyester resin: Al particles (100:0, 95:5, 90:10, 85:15, 80:20 and 75:25).

4.2 Mechanical properties

Preparation of unsaturated polyester composites reinforced by Cu or Al powder has been done by employing of all ratios (100:0, 95:5, 90:10, 85:15, 80:20 and 75:25) for each powder type. Optimization of metal powder polymer composites has been done by evaluating mechanical properties such as Tensile Strength, Bending, Impact, Hardness.

4.2.1 Tensile test results

In this work, tensile inspection was carried out mainly to investigate the Behavior of stress-strain curve for polymer composite reinforced with different selection ratios of metal particles.

4.2.1.1 Tensile test results of unsaturated polyester composite reinforced by Cu particles.

The effect of different weight percentage (5%, 10%, 15%, 20% and 25%) of Cu powder particles on the stress-strain curves of unsaturated polyester composites are shown in Figure (4.1). From this figure there was significant different in the (stress-strain) behavior as percentage of Cu powder in the prepared composite increased , the behavior was changed from (soft and weak) to (hard and tough) until the Cu powder reach to 15 wt% in the composite material, then the behavior take back to (soft and weak) that is due to reinforcement by Cu powder, which was gives more ability to resist tensile stress to this type of polymer. Also it has been observed that the fracture stress of a composite increase with increasing weight fraction of Cu powder in the range (5%-25%) as compared to plain unsaturated polyester resin. And also it has been observed that at percentage (5%, 20%, 25%) of Cu powder the fracture stress was less as compare to (10%, 15 %).

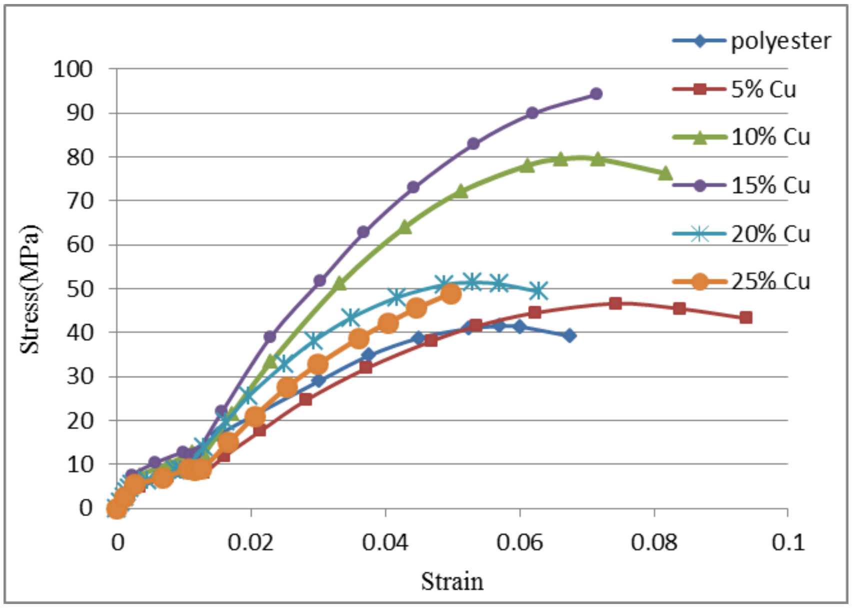


Fig. (4.1) The stress-strain curves of unsaturated polyester composites as function of copper particles content .

4.2.1.2 Tensile test results of unsaturated polyester composite reinforced by Al particles

The effect of different weight percentages (5%, 10%, 15%, 20% and 25%) of Al powder on the stress-strain curves of unsaturated polyester composites are shown in Figure (4.2). From this figure there was significant different in the (stress-strain) behavior that is depended on the Al powder content in the prepared composites, the behavior was changed from (soft and weak) to (hard and strong) when Al powder reached to 15 wt% in the composite material, then the behavior take back to (soft and weak) at the ratio 25 wt% of Al powder in the composite that is due to reinforcement by A1 powder, which gives more ability to resist tensile stress to this type of polymer. Also it has been observed that the fracture stress of a composite increased with increasing weight fraction of Al powder in the composites compare to plain unsaturated polyester resin.

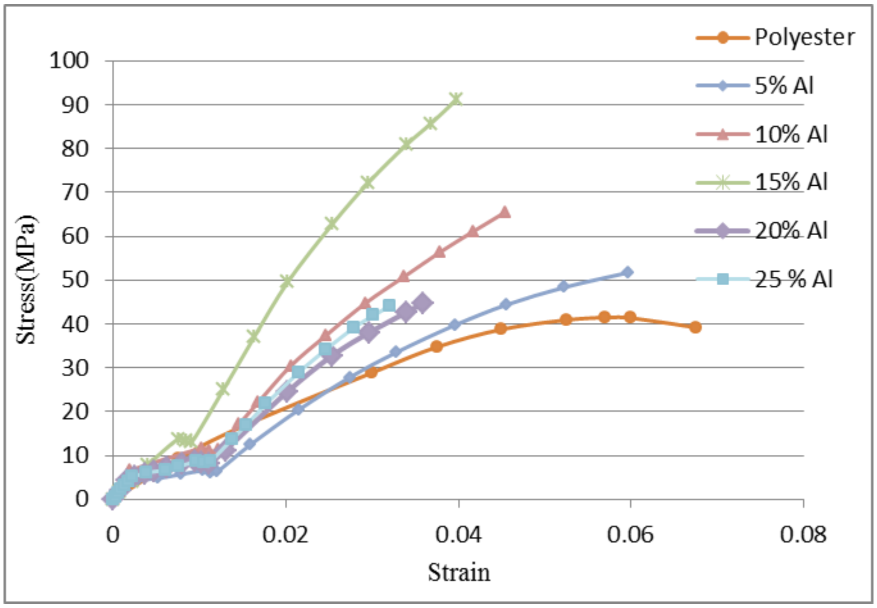


Fig.(4.2) The stress-strain curves of unsaturated polyester composites as function of Al particles content.

4.2.1.3 Tensile test results of unsaturated polyester composite reinforced by Cu and Al particles

To compare the effect of metal powder type (Cu and Al) having the same ratio (15 wt%) on the stress-strain curves of unsaturated polyester composites are shown in Figure (4.3). There was significant change occurs in stress-strain behavior for each type of unsaturated polyester composites the behavior was changed from (soft and weak) for plain polymer to (hard and tough) for unsaturated polyester composite reinforced by Cu particles and the behavior changed to (hard and strong) when polyester reinforced by Al particles. As well as from this figure it can be noticed that the fracture stress of unsaturated polyester composite reinforced by Cu particles is higher than the fracture stress of unsaturated polyester composite reinforced by Al particles due to different in the natural between these particles, in size , shape, density, the bonding force between particles and cross linking polymer and the nature of interface between each type of metal particles and thermosetting polymer [31-40].

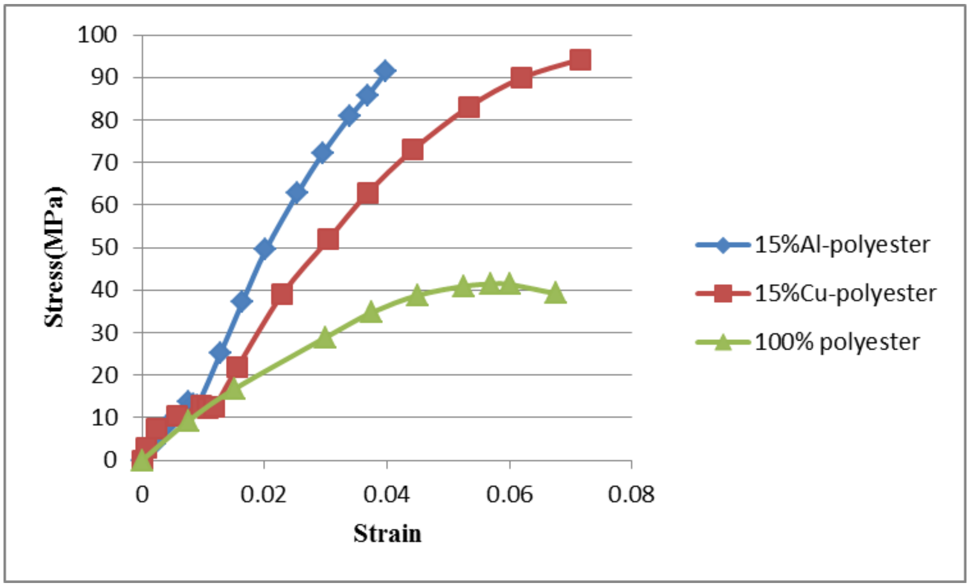


Fig.(4.3) The (stress-strain) for Al and Cu at ratio 15% and unsaturated polyester.

4.2.1.4 Tensile test characteristics

The mechanical characteristics, which include fracture stress ($\sigma_{frac.}$) and Young modulus (E), were shown in Figures. (4.4 and 4.5). It can be noticed from these figs. that there was an increase in fracture stress ($\sigma_{frac.}$) and Young modulus (E) values with the increase of Cu or Al powder in two groups of composites until the weight percentage ratio of metal powder (Cu or Al) reach to 15% wt then this values decrease with the increase of Cu or Al powder in two groups of composite until reach the ratio to 20 wt% then the these values become semi- stable as the weight percentage ratio of metal powder (Cu or Al) increase. The increase in fracture stress ($\sigma_{frac.}$) and Young modulus (E) values may be related to the nature of Cu & Al micro particles which work as nuclease to increase the crosslinking as well as these micro particles are dispersed and embedded into the polymer matrix and then filled the open structure of the amorphous crosslink structure. Furthermore, as shown from these figures (4.4, 4.5) the fracture stress ($\sigma_{frac.}$) and young modulus (E) values of the first type of polyester composite which reinforced by Cu powder slightly higher than thus values of polyester resin reinforced by Al powder and that may be related to the nature of Cu metal, which have higher mechanical properties than Al metal.

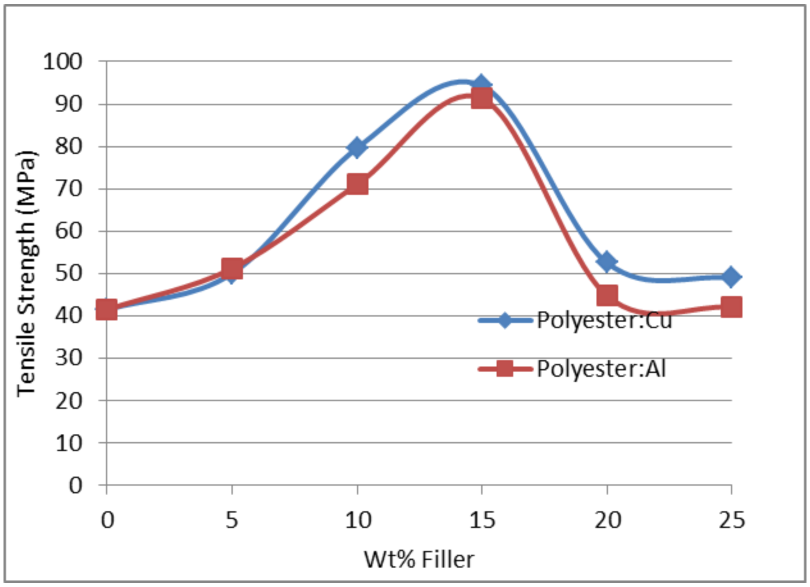


Fig.(4.4) The tensile strength of polymer composites as function of Cu or Al particles content in composites.

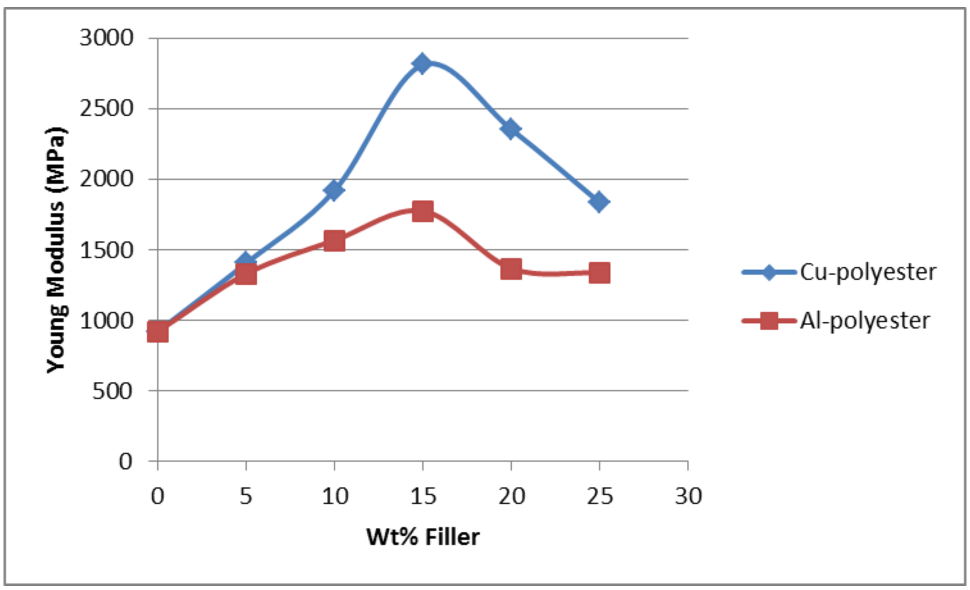


Fig.(4.5) The Young modulus of polymer composites as function of Cu or Al particles content in composites.

Whereas Fig.(4.6) shows the effect of Cu & Al ratios on the elongation values of polymer composites. It has been observed that the elongation values of unsaturated polyester resin increased as this polymer was reinforced by Cu powder except at the ratio of 25 wt% Cu powder the elongation decreased as compare to unsaturated polyester resin sample before reinforced. And also it has been noticed from this fig. that the elongation value of unsaturated polyester resin decreases when this polymer was reinforced by Al powder and the elongation values decreases with increasing of weight ratio of (Al) powder in composites samples.

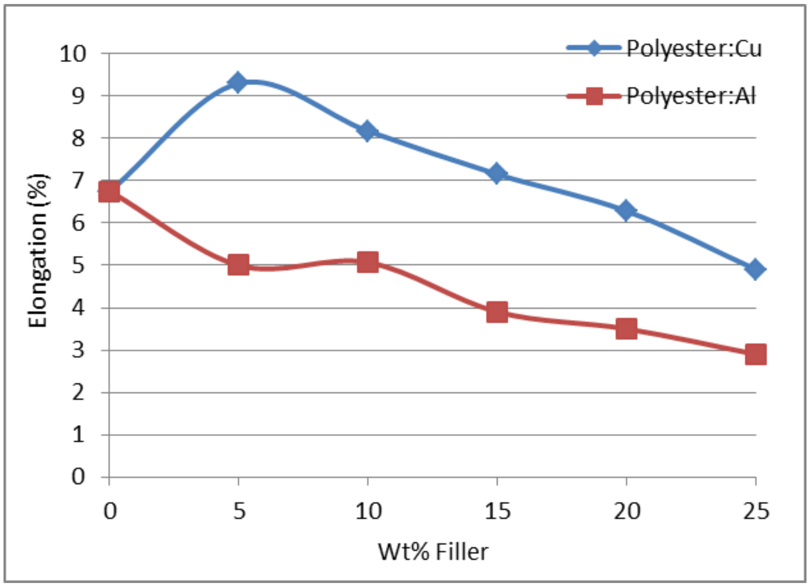


Fig.(4.6) The elongation of unsaturated polyester composites as function of Cu or Al particles content.

4.2.2 Bending test results

4.2.2.1 Bending results of polyester composites reinforced by Cu particles

The effect of different weight percentages (5% - 25%) of Cu powder on the stress-strain curves of unsaturated polyester composites for Bending test are shown in Figure (4.7). From this figure there was significant difference in the (stress-strain) behavior as percentage of Cu powder increased, the behavior was changed to (soft and weak) at 5 wt% of Cu powder in composite material, then the behavior was changed to (hard and strong) at 10 &15 wt% Cu powder in composite material as compared to plain polymer then the behavior take back to (hard and weak) at 20% and 25% Cu powder that is due to increasing of wt % content Cu powder in composite, Also it has been observed that the fracture stress of a composite decrease at 5%

weight fraction then fracture stress increases at 10% and 15% then fracture stress decrease at weight percentage (20%,25%) as compared to plain polymer.

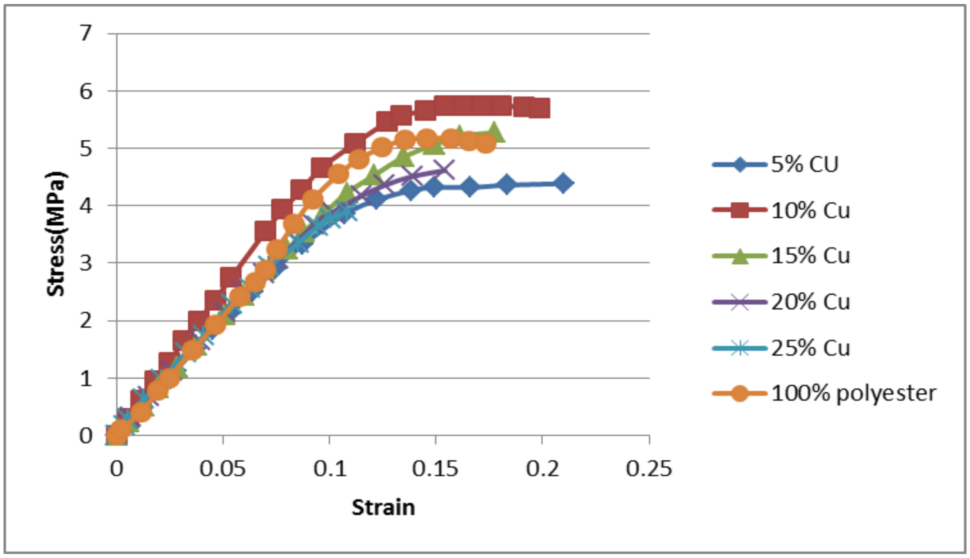


Fig. (4.7) The stress-strain curves for Bending test of unsaturated polyester composites as function of Cu particles content.

4.2.2.2 Bending results of Al unsaturated polyester composites

The effect of different weight percentages (5%-25%) of Al powder on the stress-strain curves of unsaturated polyester composites for Bending test are shown in Figure (4.8). From this figure there was significant difference in the (stress-strain) behavior as percentage of Al powder increased, the behavior was changed from (hard and strong) at100% unsaturated polyester to (hard and weak) at all weight percentages of Al powder in composite material.

4.2.2.3 Bending test characteristics

The mechanical characteristics which include fracture stress ($\sigma_{frac.}$) and Bending modulus (E_b) are shown in Figures. (4.9 , 4.10). It has been noticed from these figs. that there was an increase in fracture stress ($\sigma_{frac.}$) values at (10% , 15%) Cu and decrease at (5%, 20%, 25%) and decrease at all percentages of wt % of Al powder in composite materials as compare to plain polymer. Bending modulus (E_b) values decreased slightly at all ratios of wt % of Cu powder content in unsaturated polyester composite except 10% wt , and (E_b) values was increased at all percentages of wt % Al powder content in unsaturated polyester composite except 5% wt decreased slightly as compare to plain polymer. and that related to the natural of metal particles, the difference in particles size, particles distribution, particles shapes, surface area of particles , adhesion between particles and matrix and the depression of Cu particles as compare to Al particles [31-40].

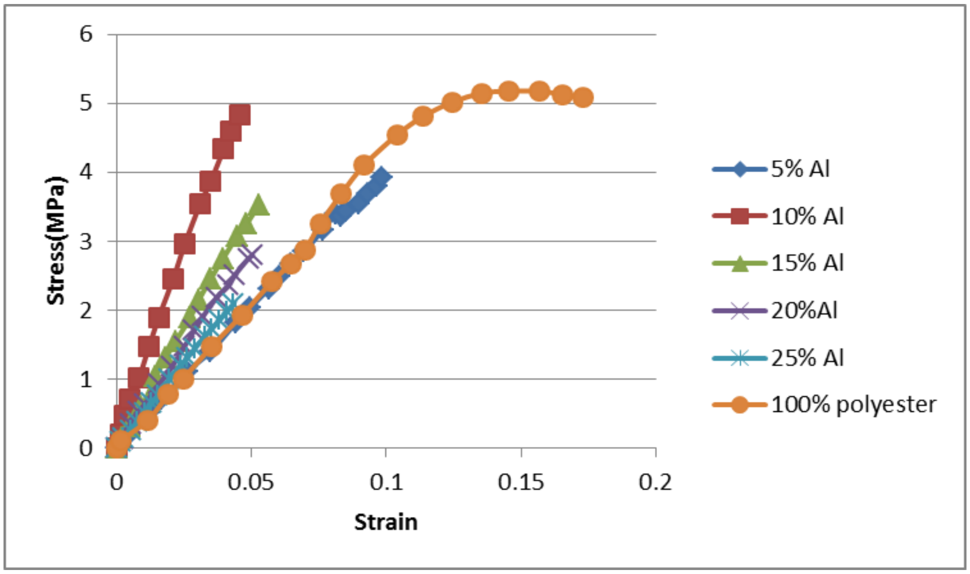


Fig. (4.8). The stress-strain curves for Bending test of unsaturated polyester composites as function of Al particles content.

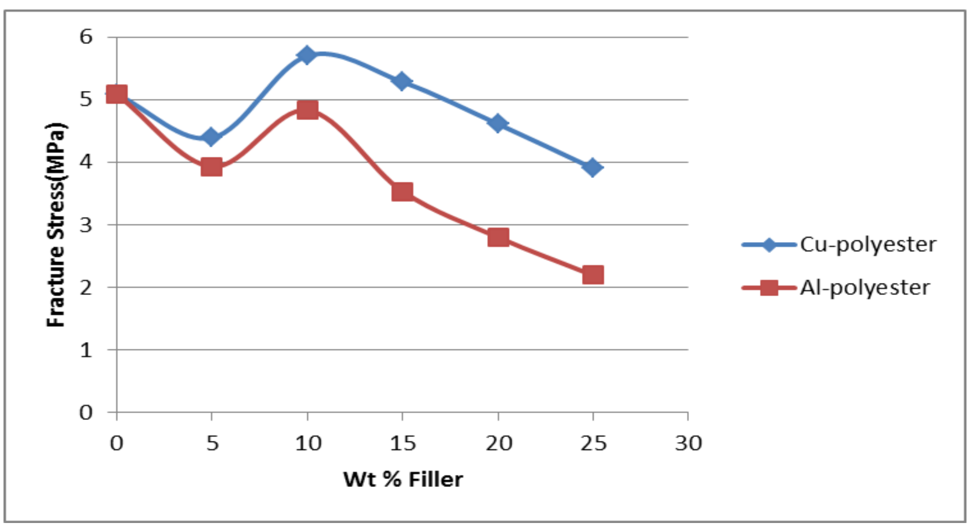


Fig. (4.9) The fracture stress of polyester composites as a function of a metal powder content.

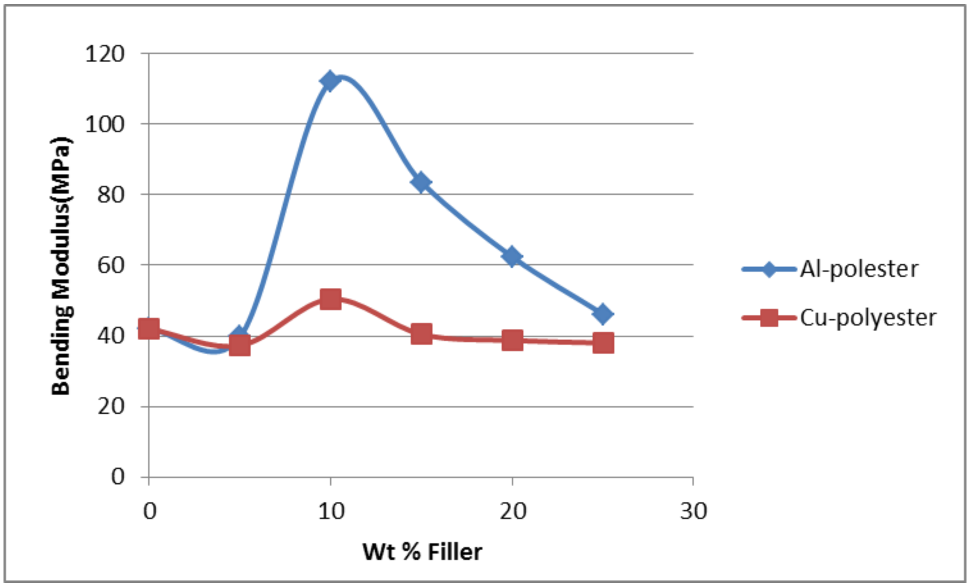


Fig. (4.10) Bending modulus of polyester composites as a function of metal powder content

4.2.3 Impact test results

The impact toughness is often the deciding factor in material selection because impact test measures the ability of polymer to withstand the load imposed upon being struck by an object at high velocity, thus it is a measure of energy required to propagate a crack across the specimen, therefore the impact properties of these samples are especially important.

4.2.3.1 Impact results of unsaturated polyester composites reinforced by Cu or Al particles

The effect of different weight percentages (5%, 10%, 15%, 20% and 25%) of Al powder and copper powder on the impact results of unsaturated polyester composites are shown in Figures (4.11) and (4.12) which were show the effect of weight ratio on impact strength (G_c) and fracture toughness (K_C) respectively, it has been observed that the required energy for sample fracture (U_C) for both groups of polymer composites decreases with increasing of weight ratio of (Cu & Al) powders in unsaturated polyester composites. And also it has been found that the (G_C) values of first type of composites reinforced by (Cu particles) it was higher than (G_C) values of the second type of composites reinforced by (Al particles) and that related to the natural of metal particles, the different in particles size, particles distribution, particles shapes, surface area of particles and the depression of Cu particles as compare to Al particles [31-40].

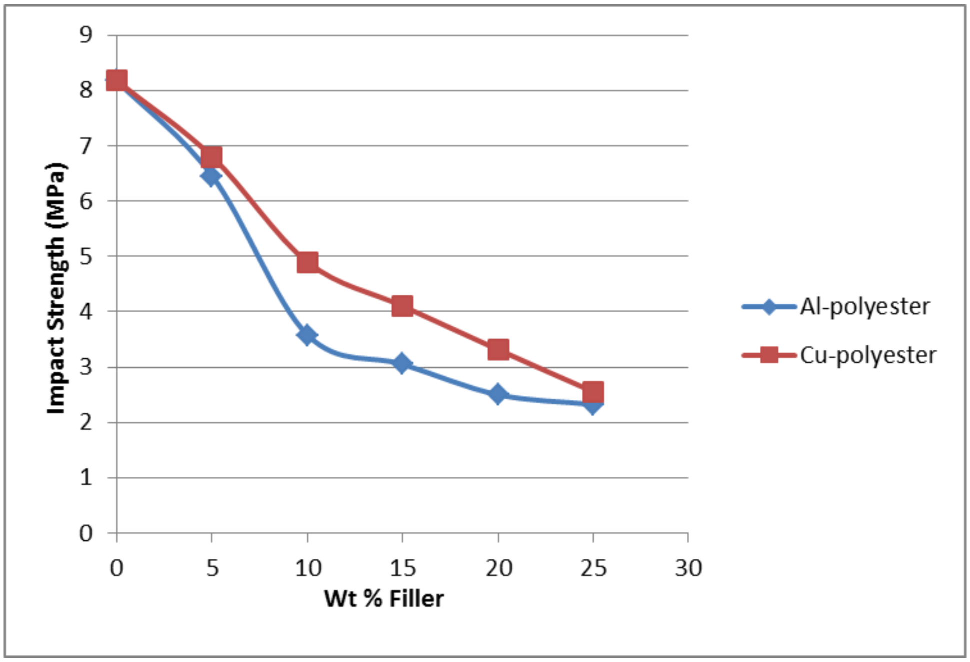


Fig. (4.11) The impact strength of polymer composites as function of Cu or Al particles content.

Also it has been observed from Fig. (4.12) that the fracture toughness (K_C) for polymer composites reinforced by Cu particles increased with the increase of Cu particles in the composites until to reach to the (15wt%) and then decreased as the weight ratio of metal particles decreased in the composite, also it has been observed that the fracture toughness for polymer composites reinforced by Al particles increased at (5wt%) ratio and then decreased as the weight ratio increased. And also it has been found that the (K_C) values of first type of composites which reinforced by (Cu) higher than (K_C) values of the second type of polyester composites which were reinforced by Al powder and that related to natural of metal particles Cu and Al in the prepared composites.

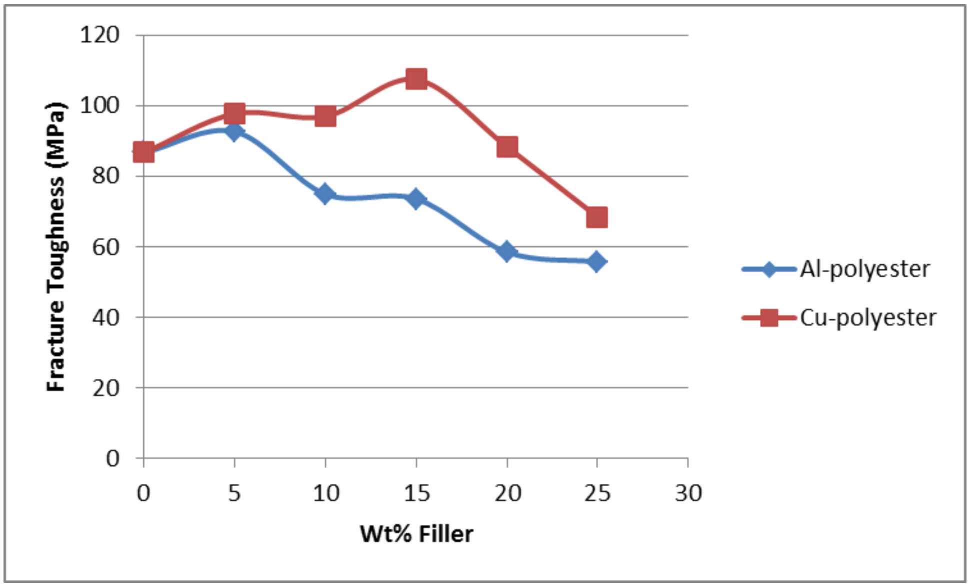


Fig. (4.12) The fracture toughness of polymer composites as function of Cu or Al particles content.

4.2.4 Hardness results of Al & Cu powder -polymer composites

Shore D Hardness of unsaturated polyester resin and its composites are shown in the Fig.(4.13). It has been found that the Shore D hardness values increase with the increase of Cu or Al particles content in the polymer composite and from this figure it was observed that there was sharp increase in hardness values as Cu or Al particles increase in polymer matrix until reach to 15wt% and then become semi- stable as the metal particles increase in the polymer composite, the increase in hardness value may be related to the nature of Cu & Al micro particles which work as nuclease to increase the crosslinking as well as this micro particles are dispersed and embedded into the polymer matrix and then filled the open structure as the amorphous crosslink structure [31-40]. Furthermore, hardness values of the second type of polyester composite reinforced by Al particles were slightly higher than hardness values of composites reinforced by Cu particles and that related to the particles size of Al particles which are smaller than Cu particles as shown in figs (3-1) and (3-4).

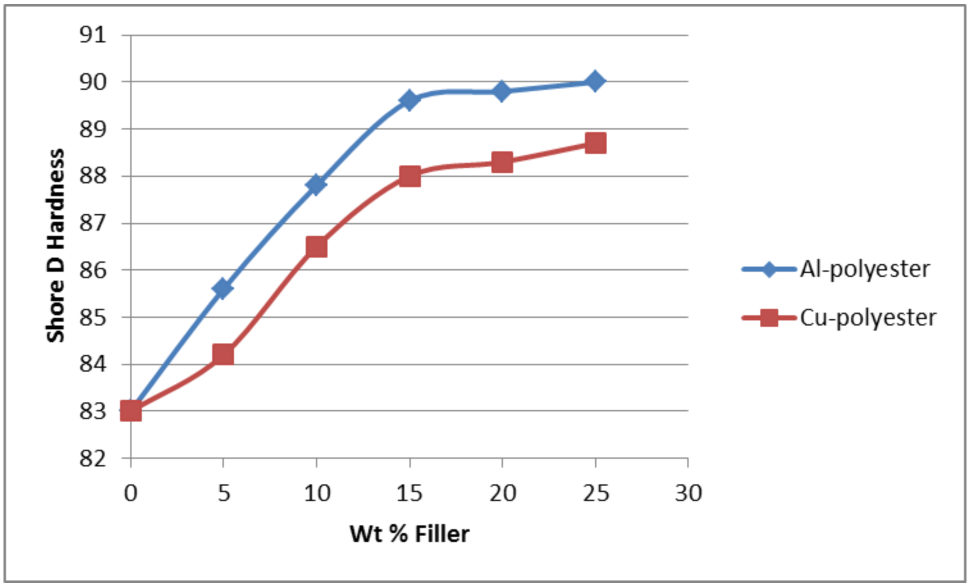


Fig.(4-13) Shore D hardness of polymer composites as function of Cu or Al particles content.

4.3 Physical Test

4.3.1 Thermal conductivity of Cu & Al polymer composites

It has been realized from Fig. (4.14) that the thermal conductivity (k) increased as the Al and Cu powders weight ratios increased for both types of polymer composites which reinforced by metal powders, and the value of (k) for polymer composite reinforced by Cu is higher than the polymer composite reinforced by Al powder as shown in Fig.(4.14) because the thermal conductivity of Cu metal 401 W/(m.^{o}C) is higher than thermal conductivity of Al powder which equal to 250 W/(m.^{o}C) [41-43].

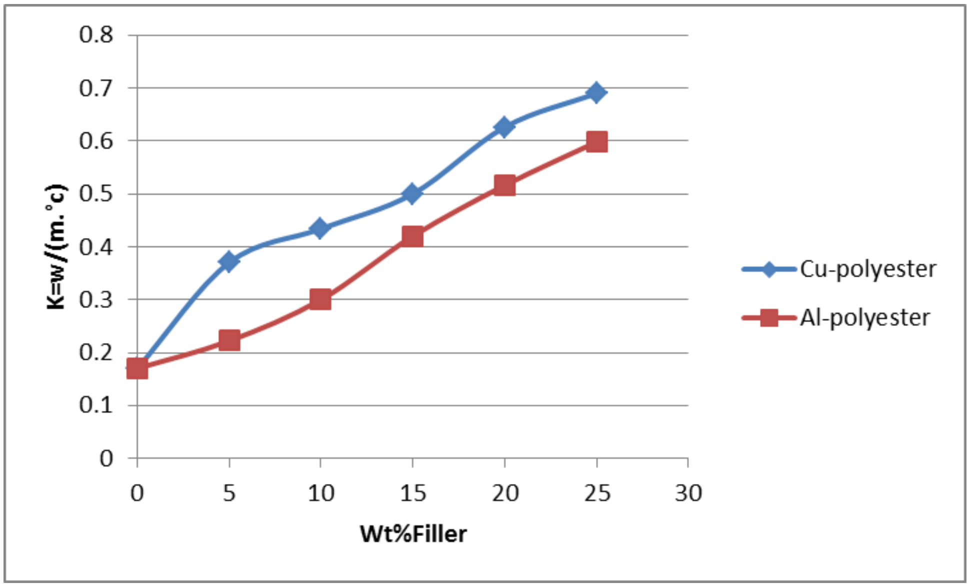


Fig.(4.14) Thermal conductivity of polymer composites as a function of a metal powder content.

4.4 Morphology test

4. 4.1 Optical microscope analysis

The changes in surface morphology are evaluated for the following prepared samples

1.unsaturated polyester composite reinforced by copper particles.

2. unsaturated polyester composite reinforced by Aluminum particles.

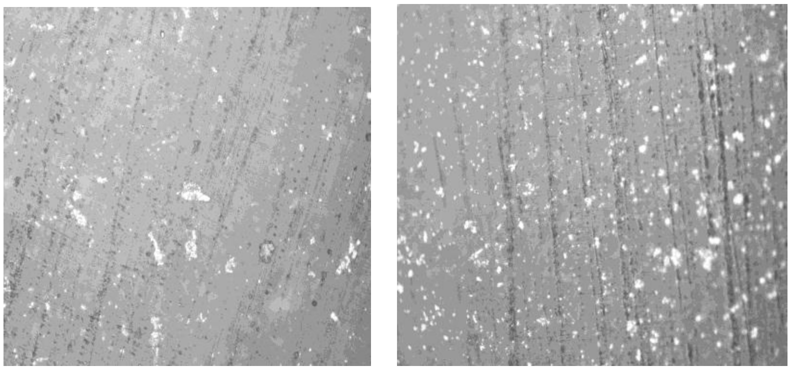
These samples were subjected to optical microscopy studies, table (3.1) shows optical microscope instrument. The morphology of unsaturated polyester composite reinforced by metal particles depends on the nature of the components, ratios, nature of particles, particles size, particles shape and processing conditions [31-43].

Optical micrographs of samples Figs. (4.15) and (4.16) show the morphology of unsaturated polyester composites prepared. For comparison, these micrographs clearly show that there was difference in the morphology of unsaturated polyester composite reinforced by copper particles and unsaturated polyester composite reinforced by Aluminum particles. Also the morphological results clearly show that the unsaturated polyester matrix which was reinforced with the different loadings of metal particles for two groups powders, depends upon the nature, size and the distribution of the particles reinforcement, from micrographs figs. (4.15, 4.16) it can be observed. However, the distribution and interaction between the metal particles and the matrix is a better. This notice has been observed from Morphological results because the bonding force between metal powders (Cu and Al) and polymer matrix , the bonding force between metal powder and matrix depend on many factor adhesion between matrix and metal particles, particles size, physical properties of particles, particles shape, particles surface area, the direction of bond which depends on crosslinking network of polymer, volume fraction of metal powder, conditions of processing (ambient temperature, humidity of atmosphere, mixing method, mixing time before and after adding the hardener, casting time, casting method, hardener percentage, hardening time) [31-43].

From micrographs it has been observed that the concentration of particles increase with increasing wt% of metal powder for both type of composites, the number of particles per unit area and the agglomeration in Al composite is more than Cu composite because of different density between these metals, the density of Cu is higher than Al which leads to difference in volume fraction. The volume fraction of Al particles for every percentage of composite is higher than volume fraction in Cu particles in composite.

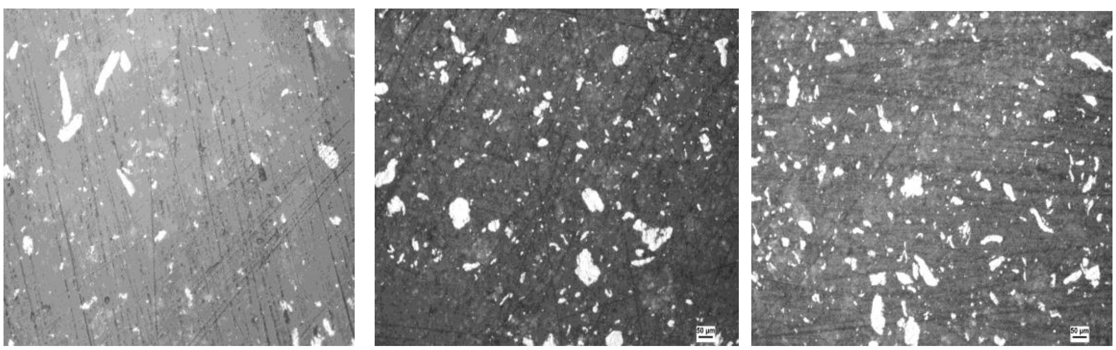
200x 5 % Cu　　　200x 10% Cu　　　200x 15% Cu

Figure (4.15.A) Optical photomicrographs of unsaturated polyester reinforced by copper powder particles.

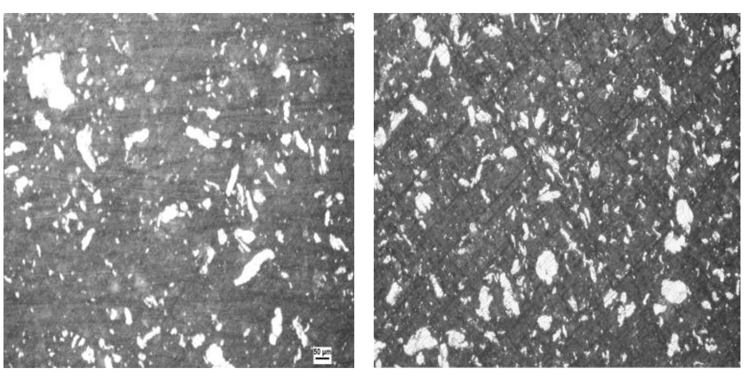


200x 20% Cu 200x 25% Cu

Figure (4.15.B) Optical photomicrographs of unsaturated polyester reinforced by copper powder particles.



200x 5% Al 200x 10%Al 200x 15%Al



200x 20%Al 200x 25%A

Figure (4.16) Optical photomicrographs of unsaturated polyester reinforced by Al powder particles.

5.1 Conclusions

In the present work using the inorganic fillers as the metal powders viz. Cu and Al particles added to the thermoset polymer to improve its mechanical properties such as strength and it has been concluded the following:

1- The mechanical properties of the composite were found to be a function of the natural particles, size, aspect ratio, the dispersion, the particles orientation, the interfacial interaction between the minerals and the polymer matrix.

2- There is a significant increment in the tensile strength and modulus with an increase in the filler concentration (Cu and Al particles).

3- The impact strength decreases with concentration of filler due to the reduction of elasticity of material due to filler addition and thereby reducing the deformability of matrix.

4- Addition of metal powders (Cu and Al) improved the thermal properties such as the thermal conductivity values (K) of the polymer composites due to high conductivity of metal powder as well as the uniform distribution of these particles in the matrix

5- Morphological studies showed that there is a good interaction between the metal particles and the matrix. The agglomeration increases with increasing weight percentage for each type of composites, but the agglomeration in Al composite is higher than Cu composite due to increase in the volume fraction which is related to the density of the metal powder, the density of Cu is more than Al which leads to higher volume fraction of Al than Cu.

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