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# IMPROVE EPOXY TOUGHNESS BY ADDING TOUGHENING AGENT FOR COATING APPLICATION

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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## ABSTRACT

Epoxy is one of the most polymers used in a variety of applications due to its amorphous structure with a prime hardness and mechanical strength. But it is suffer from the high hardness and brittleness so it need to be improved its flexibility and toughness. In this project an epoxy/polyol blend were prepared with different amounts of polyol (1%, 3%, and 6% wt.). The blends were prepared using mixing of epoxy/polyol/hardener. The FTIR, tensile strength, impact strength, hardness, and fracture toughness were used to characterizing the blends. Results show that there is no change in FTIR curves. Mechanical properties results show that the tensile strength, elastic modulus, and hardness were decreased with polyol addition. Both fracture toughness and impact strength were improved with polyol addition.

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# Chapter One

the introduction

## 1. Introduction

A polymer is a giant chemical compound composed of repeating units of identical or different monomers with or without loss of material. Compared to the thermoset material, the thermoset polymer is a more resilient polymer because its cross-linking occurs in three directions. Epoxies are thermoset polymers that are cured with a variety of curing agents, commonly referred to as hardeners. Epoxy resin is used in many applications due to its amorphous thermosetting material with an original hardness and strength. Unfortunately, cured epoxy systems have one major disadvantage: significant brittleness, poor crack resistance, and poor resistance to crack initiation and propagation. This severely limits their use in applications that require high fracture toughness. Much effort has been made to improve their physical properties through the use of various chemicals that act as hardeners or reinforcing agents. There are several ways to improve the strength of epoxies such as: plasticizing the polymer, inducing an interpenetrating network (IPN), and introducing a well-dispersed second phase of one of two things: soft rubber particles or stiff inorganic particles. Blending of polymers can be an inexpensive method to develop a material with specific properties based on customer requirements. In the case of polymer blends, all components are polymeric, which means that both the matrix and the secondary component are deformable above the glass transition temperature of for amorphous polymers or above the melting point of semi-crystalline polymers. Organic compounds with adhesive properties are often used as corrosion inhibitors for metals in various industries such as aerospace, automotive, architecture, ships and oil tanks to name a few. In most cases, they are applied as a thin layer to the metal surface to prevent corrosive chemicals from penetrating the metal surface. Among the organic compounds, those based on epoxy resins are among the most widespread due to their functional properties and adaptability. Epoxy resin was chosen for the coating due to its versatility; It can be used to protect metal and concrete structures, electrical components, construction adhesives and more. Metals protected with epoxy are susceptible to wear and surface abrasion due to the complex network structure of pure epoxy that protects the metal. The corrosion is quite low. Polymer composites are widely used in engineering, apart from structural elements where they are subject to wear. It is very effective in improving the properties of polymer composites, especially their friction and wear properties, by incorporating well-dispersed inorganic

particles into the polymer matrix. This improvement has proven to be very effective. Various researchers have attempted to increase the strength of the epoxy system using different cure modifiers. Other researchers have attempted to improve the tribological properties of the pure epoxy matrix by adding various types of micro- and nanometer-scale fillers to obtain composite coatings.

## 1.2 Literature Review

In 13 June 2022, xinyu shang, lei xue. studied Toughness Improvement of Epoxy Composites Using a Kind of Environment-Friendly Bio-Based Polyester Polyol Epoxy resin (EP) is a thermosetting resin with prominent performances and wide applications. However, the inherent brittleness limits its development in the engineering materials area. A liquid bio-based polyester polyol (LLP) with flexible long chains was synthesized in this study by melt polycondensation of corn straw lignin. After being compounded with EP (LLP/EP), the mechanical property, micromorphology and thermal behavior of the composite were evaluated. The experimental result indicated that the fracture brittleness of EP composite was decreased by importing the LLP. The bending and impact strength were up to 113.67 MPa and 51.29 kJ/m<sup>2</sup> for 10%-LLP/EP, which were 5.25% and 27% higher than those of unmodified EP. The results of this work build new avenues for the efficient utilization of lignin and the development of low-cost, high-performance and well environmentally adaptable EP composite by renewable resources.

In 7 May 2022, yong wen, xudong liu, studied Improving Epoxy Resin Performance Using PPG and MDI by One-Step

Modification. The toughening modification of epoxy resin by polyurethane prepolymer (PU) can effectively solve the disadvantage of high brittleness in its application. In this study, a convenient way to toughen epoxy resins was explored, and the monomers PPG and MDI for the synthesis of polyurethane prepolymers were used for a one-step modification of epoxy resins. The test results of viscosity and elongation at break showed that P-M reduced the viscosity of the epoxy resin and improved the toughness. Especially when the content of P-M was 25%, the elongation at the break of the modified EP reached 196.56%. From a

thermogravimetric and pyrolysis kinetic analysis, the P-M modification had better thermal stability than the PU modification. These findings have particular implications for the toughening and engineering applications of epoxy resins.

In 8 December 2012 , Muhammad M. Rahman, Mahesh Hosur, studied Mechanical characterization of epoxy composites modified with reactive polyol diluent and randomly-oriented amino-functionalized MWCNTs. Increased fracture toughness of diglycidyl ether of bisphenol A (DGEBA) type epoxy resin was obtained without compromising other desired mechanical properties, such as strength and stiffness, by combining the benefits of adding polyether polyol and amino-functionalized multi-walled carbon nanotubes (NH<sub>2</sub>-MWCNTs) simultaneously. The effect of concentration on the morphology of three-phase nanotube/polyol/epoxy composites was investigated using scanning electron microscopy (SEM). Mechanical properties were evaluated by three point flexure and single edge notch bend (SENB) fracture toughness tests. Addition of a polyether polyol to the epoxy resin increased mode-I fracture toughness and flexural strain energy, while adversely affecting flexural strength and stiffness. A synergistic effect was observed with the addition of amino-functionalized multi-walled carbon nanotubes (NH<sub>2</sub>-MWCNTs) into polyol toughened epoxy, with significant improvements in fracture toughness and strain energy as well as in flexural strength and stiffness. Matrix plastic deformation and lower crosslink density due to polyether polyol in the epoxy system increased toughness while reducing flexural strength and stiffness. However, incorporation of uniformly dispersed 0.3 wt.% loading of NH<sub>2</sub>-MWCNTs into the polyol-toughened epoxy composites improved the mechanical properties as well as fracture toughness, compared with pristine epoxy and polyol-toughened epoxy.



# Chapter two

The theoretical part

## 1. thermoset polymer

Thermoset polymers (also called thermoset) are a family of plastic materials characterized by being formed from a liquid solution that irreversibly forms a solid material during the heating phase. This chapter focuses on some aspects of epoxy polymer chemistry as it includes examples of stepwise and chain polymerizations used in the synthesis of polymer networks. The chapter explains the structural transformations such as gelation, vitrification, etc. that occur during network formation. He then talks about the transformation principles of thermoset polymers. Techniques for processing thermosetting polymers for a wide variety of applications are described below. Solid thermoplastic (thermoplastic) is a term given to a special type of polymer that hardens to a harder state than the first state when exposed to energy. This energy can take the form of heat (often in excess of 200°C), a chemical reaction (e.g. two parts of an epoxy), or exposure to radiation. Thermoset materials are often ductile or malleable before curing, are formed into the desired shape after curing, and are also used as binders. Macromolecules structure.png Polymer resins can be processed into elastomers or rubber by crosslinking. Heat is also used to obtain point mass. Magnetic materials do not melt when exposed to heat after curing. Electrothermal materials are generally harder than thermoplastic materials. Support for high temperature applications. They are difficult to process, similar to thermoplastics, which can be formed.

### The main applications of thermosets :

matrix composites in building and construction include adhesives and sealants, thermal insulation, roofing, piping, bridge structures, and repair and rehabilitation of civil structures.



## 2.2 Epoxy

As a kind of good-performance thermoset, epoxy polymer systems are widely employed like a matrix material in industries including vehicles, electronics, and aerospace. To get this kind of versatility, you need to choose an epoxy resin/hardener system that works well and then process it according to a good curing schedule . Because of their great adherence to a wide different of substrates, high heat and chemical resistance, and high mechanical characteristics, epoxy polymers are often utilized as thermosetting substances . These materials are manufactured by the chemical change of multifunctional epoxy monomers, which results in the formation of a polymer network that is produced in an irreversible manner . Coatings, adhesives, electrical insulation, construction, and composites are just a few of the many applications for epoxy resins. Although coatings account for more than half of all epoxies' applications, epoxy composite materials are a growing field in their own right . New materials are being employed in a broad variety of sporting equipment and have even become a deciding element in high-level competition. Its widespread adoption can be attributed to the significant performance improvements it brings to sports equipment thanks to the various new materials' excellent characteristics, such as high specific strength, specific modulus, lightweight, wear resistance, and so on. several cutting-edge materials, including carbon fiber and epoxy resin composites, nylon fiber composites, and unsaturated polyester composites .

Some of the aspects in which epoxy is different from other polymers are as follows:

- good mechanical characteristics,
- resistance to chemicals, moisture, and corrosion,
- Thermally efficient,
- Superior adhesion,
- excellent dielectric resistance;
- little shrinkage after curing,
- Its low viscoelasticity
- excellent dimensional stability,

- high degree of machinability

### 2.2.1 Epoxy Resin Curing

There are a number of crosslinking reactions that can transform epoxy resins from their flexible thermoplastic state into brittle, hard, thermoset solids . Hardeners are used to harden epoxy resins, turning them into a strong, infusible, and insoluble three-dimensional thermoset network. The use of suitable crosslinking agents, also called hardeners or hardeners, in combination with the appropriate epoxy resins ensures the best possible performance properties. Field process expertise, pot life, curing environment, and desired physical properties all play a role in selecting the best curing agent. Hardeners affect not only the viscosity and reactivity of the formulation, but also the type of chemical properties produced and the degree of crosslinking that occurs. As a result, these factors affect the quality of thermosets. Resistance to chemicals, electricity, mechanical stress and temperature. The epoxy and hydroxyl functional groups of epoxy resins are responsible for the chemical reactivity of the material. When the epoxide groups react, the oxirane ring opens and linear C–O bonds form. This property is responsible for epoxy resins. excellent dimensional stability after curing and minimal shrinkage. Heat is required for efficient curing of and devolatilization when polycondensation cures via hydroxyl groups, typically resulting in the formation of volatile by-products such as water or alcohol .

### Applications of Epoxy Resin

Epoxy resins are multipurpose construction materials and coating agents due to their excellent qualities, which include resistance to humidity and chemicals, good adherence to different substrates, and outstanding mechanical features. Epoxy resins may be used in three major areas:

- Coatings
- Adhesives
- Construction and structural materials

### 2.2.2 Epoxy as a coating

Epoxy is used as an insulating coating for water leaks in underground reservoirs and sewage wells, and is sometimes used for waterproofing roofs and houses. Heavy-duty two-part epoxy coatings have been developed on metallic substrates and use less energy than heat-curing powder coatings. These systems provide a strong, protective coating with excellent toughness. One part epoxy coatings are formulated as an emulsion in water and can be cleaned up without solvents.

Epoxy coatings are often used in industrial and automotive applications because they are more heat resistant than latex and alkyd-based paints. Epoxy paints tend to deteriorate, known as "chalking," due to exposure to ultraviolet light.

A change in color, known as yellowing, is a common phenomenon for epoxy materials and is often a concern in art and conservation applications. Epoxy resins yellow over time, even when not exposed to UV light. Significant advances in understanding epoxy yellowing were made by Down first in 1984 (natural dark aging) and later in 1986 (high intensity light aging). Down investigated several room temperature curing epoxy resin adhesives suitable for use in glass preservation, testing their tendency to yellow. A fundamental molecular understanding of epoxy yellowing was achieved, when Krauklis and Echtermeyer explored the mechanical origin of yellowing in commonly used epoxy amine resins, published in 2018. They found that the molecular cause of epoxy yellowing was the thermal oxidation evolution of carbonyl groups in the polymer's carbon-carbon backbone via attack A radical nucleophile.

Polyester epoxies are used as a powder coating for washers, dryers, and other "white goods". Fusion epoxy (FBE) powder coatings are widely used for the corrosion protection of steel pipes and fittings used in the oil and gas industry, potable water (steel) pipelines, and concrete reinforcement. Epoxy coatings are also widely used as primers to improve the adhesion of automotive and marine paints especially on metal surfaces where corrosion (rust) resistance is important. Metal cans and containers are often epoxy-coated to prevent rusting, especially for acidic foods such as tomatoes. Epoxy resins are also used in decorative flooring applications such as terrazzo floors, laminate floors, and colored aggregate floors.

Epoxies were modified in a number of ways, reacting with oil-derived fatty acids to produce epoxy esters, which were treated in the same way as alkyds. of which L8 (80% linseed) and D4 (40% dried castor oil). It was often reacted with styrene to make epoxy styrene esters, which are used as pre-feeds. Phenolic treatment to make cylinder liners, esters treatment with amine resins and epoxy pretreatment with amino resins to make resistant top coats. One of the best examples of this was the system for using solvent-free epoxies to prep ships during construction, this used a ventilated hot spray system with pre-mixing at the head. This avoided the problem of solvent retention under the film, which later caused adhesion problems.

### **2.2.3 Epoxy Resin Toughening**

The main disadvantage of epoxy resin is that it is very brittle due to its highly cross-linked network . Additionally, the inherent brittleness of epoxy resins prevents them from being used in many high-tech, high-strength applications, such as aerospace adhesives and fiber-reinforced polymers. apartment This severely limits the possible uses of epoxy resins . For all these reasons, the highly cross-linked microstructure of epoxy resin makes it very brittle and hence epoxy resin exhibits low resistance to crack initiation and propagation .Epoxy resin has a fracture energy that is two or three orders of magnitude lower than that of thermoplastics and metals. This suggests that epoxy resin needs to be harder to allow for a wider range of applications. The crack resistance of epoxy resins has been the subject of extensive research and development in recent years . There are many ways to increase the strength of epoxy polymers, such as plasticizing, creating an interpenetrating network (IPN), and adding a well-dispersed second phase consisting of soft rubbery particles or hard inorganic particles. Particles . Addition of a second phase consisting of materials such as thermoplastics, block copolymers and hard or soft particles is a commonly used technique for this purpose .When inorganic or organic particles are used, the resulting epoxy polymer is referred to as "particle-filled epoxy resin". On the other hand, when using soft rubber particles, the glass transition temperature (Tg) is much lower than under service conditions. The process of adding a second gum phase is commonly referred to as "gum dipping". method .

## 2.2.4 Unmodified Epoxy Fracture Behavior

The epoxies, in their unaltered forms, break easily and brittlely, tensile stress is the most prevalent and causes fracture, and the issues of stress concentration noticeable flaws (cracks) appear. Traditionally, linear elastic fracture mechanics (LEFM) has been used to investigate the fracturing behavior of these epoxies, This is due to the fact that these materials are very brittle and only undergo localized plastic deformation when broken. Thus, the strength of epoxies is often quantified by calculating the critical strain-energy release rate, fracture energy (the amount of energy per unit area required to initiate a crack), or critical stress intensity factor (K<sub>IC</sub>). When doing so, make sure the plane strain situation is minimal.

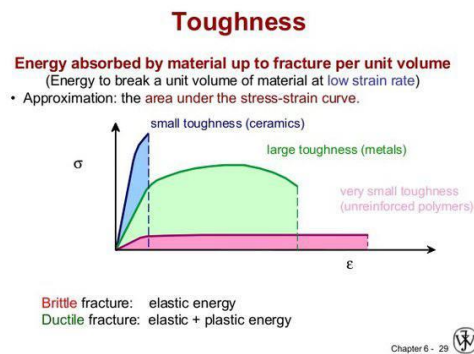
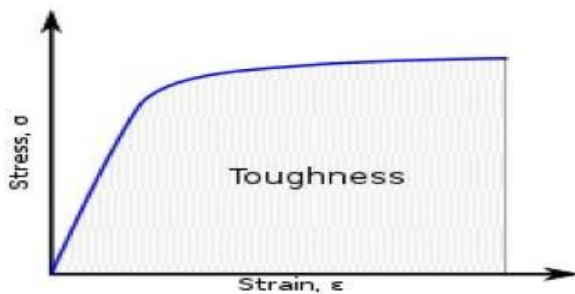
## 3. Polyol

In organic chemistry, a polyol is an organic compound containing multiple hydroxyl groups (–OH). The term "polyol" can have slightly different meanings depending on whether it is used in food science or in polymer chemistry. The polyols containing two, three, and four respectively. hydroxyl groups are the diols, triols, and terols,

Polyols can be classified according to their chemistry. Some of these chemicals are polyethers, polyesters, polycarbonates and also acrylic polyols. Polyether polyols can be further subdivided and classified as polyethylene oxide or polyethylene glycol (PEG), polypropylene glycol (PPG) and polytetrahydrofuran or PTMEG. These contain 2, 3 and 4 carbons respectively for every oxygen atom in the repeat unit. Polycaprolactone polyols are also available commercially. There is also a growing trend to use bio-based (and therefore renewable) polyols.

## Toughness polymer :

Polymer toughness, i.e., the ability of a polymer to exhibit plastic deformation and resistance to an impact load without failure, is a very desirable property of a material or product.



The area is located under the radiation of stress and agitation. To be solid, to be strong and spreadable. For example, brittle materials (such as ceramics) that are strong but have limited ductility; On the contrary, the deserts. To be solid you must make it high firm and high stress. Generally speaking, toughness refers to the operating force that can support it operate. Unfortunately, cured epoxy systems have one major drawback: significant brittleness, demonstrating low fracture toughness and poor resistance to crack initiation and propagation. This severely limits their applicability in applications needing high fracture strength . There have been a lot of efforts made to enhance their physical properties by applying a variety of different chemicals that are toughening or strengthening agents . There are a few different ways that the toughness of epoxy resins may be improved, e.g., plasticization of the polymer, induction of an interpenetrating network (IPN), and the insertion of a second, well-dispersed phase of one of two things: soft rubbery particles or rigid inorganic particles . Polymer blending can be a cost-effective method for developing a material with specific properties according to customer requirements .



# Chapter three

Experimental part

## 1. Introduction

This chapter discusses all the experimental process and devises that used to obtained the experimental test, Hardness, FTIR , tensile strength and impact energy and fracture toughness.

## 3.2 material

The materials for this project were provided with epoxy resin and use the polyol from the polymers department laboratories, and the tests were also examined in the department laboratories.

## 3.3 Sample Preparation

**The first step:** prepare the basic materials, which are epoxy resin, polyol additive, and the tools used are measuring cups. mixing bowl. Protective equipment (gloves, mask and respirator). As well as the casting mold.

**The second step:** the added ratios of epoxy resin and hardener are 2:1, and the ratio of polyol added to the epoxy resin is (0%,1%,3%,6%). The chosen weight of the epoxy material to make the sample is (150g). Measuring these quantities with an accurate and sensitive scale as in figure(1). The table(1) below shows the addition of polyol to epoxy resin:

N.of sample	%of polyol	Epoxy (g)	Hardness (g)	Polyol (g)	Epoxy + polyol (g)
1	0%	100	50	0	150
2	1%	99	49.5	1.5	150
3	3%	97	48.5	4.5	150
4	6%	94	47	9	150

Table (3-1) below shows the addition of polyol to epoxy resin



Figure(3-1) : A laboratory micro-sensitive balance

**Step Three:** After completing the weighing of the materials, put the epoxy resin, hardener, and additive according to the proportions in table (1) in a glass container, and then mix the material in a mechanical mixer well for ten minutes as in figure(2).



Figure (3-2): mechanical mix

**The fourth step:** After the mixing process, the mixture is placed in the vacuum device for 10-15 minutes at room temperature, in order to remove the bubbles present on the surface of the mixture or inside the material.as in figure (3).



Figure (3-3) vacuum device

**Step Five:** After the process of removing bubbles from the mixture, the mixture is ready for the casting process. The mixture is placed in a mold made of silicone rubber to prevent the sample from sticking to the mold. The curing process is left for 24 hours.

**Step Six:** After the treatment process, the surface of the sample is cleaned and Be ready for mechanical tests .



### 3.4 The devices used

#### 3.4.1 Tensile testing device:

Instron 5556 universal testing machine as per ASTM D-638 IV is utilized to perform the tensile behavior, Four specimens were examined and the mean value was considered. The crosshead speed was 5 mm/min with 5KN as the load applied Figure (4).



FIGURE (3-4) TENSION DEVICE

#### 3.4.2 Impact test device :

Impact test was performed according to ASTM D-256-87 by using CEAST resil impact German, gant (HAMBURG) company (model WP 400 charpy type instrument). All specimens were fixed in a cantilever position, then the pendulum arm strokes, the energy absorbed by the specimens in joule unit. The calculation of Impact strength can be done by the following equation Figure (5).



**FIGURE (3-5)** IMPACT DEVICE

### 3.4.3 Hardness tester device

Such as many other hardness tests, durometer is a measuring the depth of an indentation in the material generated by an applied force on a standardized presser foot. The residual depth in the material depends on the hardness of the material, its viscoelastic properties, the form of the presser foot, and the duration of the test. The initial hardness or the indentation hardness after a specific time are characterized using ASTM D2240 durometers Figure (6).



**Figure (3-6)** Hardness device / shore D

### 3.4.4 FTIR tester device :

The test of FTIR was achieved using a Fourier transform infrared spectrometer and was used to obtain specific information about the chemical bonds and molecular structure of epoxy system samples. The (FTIR) test is performed according to (ASTM E1252) by using FTIR instrument type IR Affinity-1 (made in Japan)[123]. It is available in the laboratory of the Materials Engineering Faculty/Polymer Engineering and Petrochemicals Industries Department/ University of Babylon. It is supplied with a DTGS detector that operates at ambient temperature and a KBr beam splitter. The infrared spectrum was used within a range of (400–4000) $\text{cm}^{-1}$ . For figure (7).

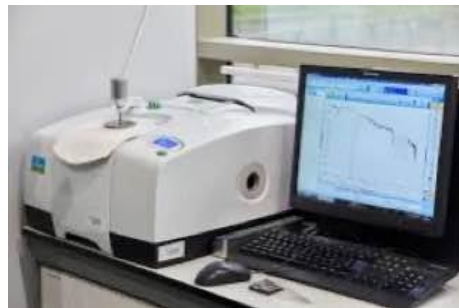


Figure (3-7) FTIR device

### 3.4.5 Fracture toughness device

The fracture strength is measured according to international specifications with the previously used tensile device. STM D5045 is one of the standards that can be used to measure the fracture toughness of epoxy, which is a commonly used thermoset polymer in various applications such as adhesives, coatings, and composites. The test involves creating a pre-crack in the epoxy sample and then applying a controlled load to propagate the crack. The energy required to propagate the crack is measured and used to calculate the fracture toughness of the epoxy.

# Chapter four

Results and discussion



## 4.1 Introduction

This chapter includes a thorough analysis of all the findings from the experimental work. The outcomes of FTIR and mechanical tests, such as tensile, fracture toughness, impact, and hardness tests, are included.

## 4.2 Fourier Transform Infrared Spectroscopy (FTIR) Results of Blends

The color change of the epoxy used in this study was observed from transparent white to dark white after the addition of polyol, so we thought that it was possible to form entangled bonds within the epoxy network due to polyol, and this necessitated an FTIR test. The FTIR test was carried out for two samples, the first for epoxy and the other for the blend ( epoxy – polyol ) as shown in figures 4.1 and 4.2 . It turned out from the two tests that there is no new bonds formed due to the addition of polyol, and this indicates that the darkness formed in the epoxy is caused by the penetration of polyol between the epoxy bond network as shown in table (4.1)

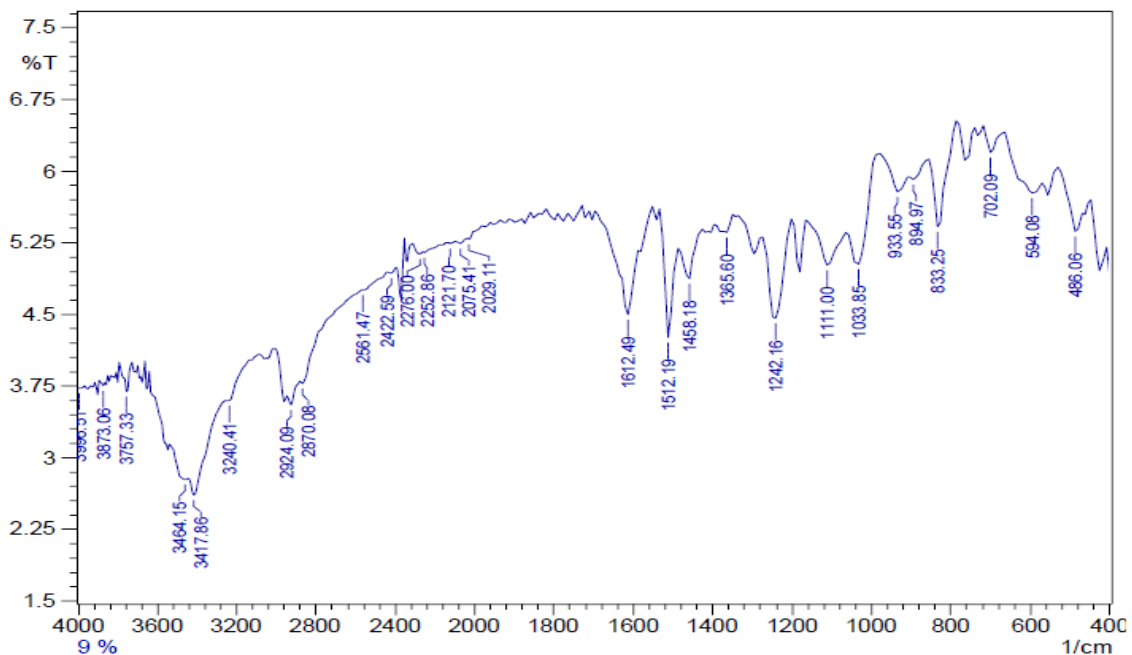


Figure 4-1 the FTIR Spectrum for epoxy

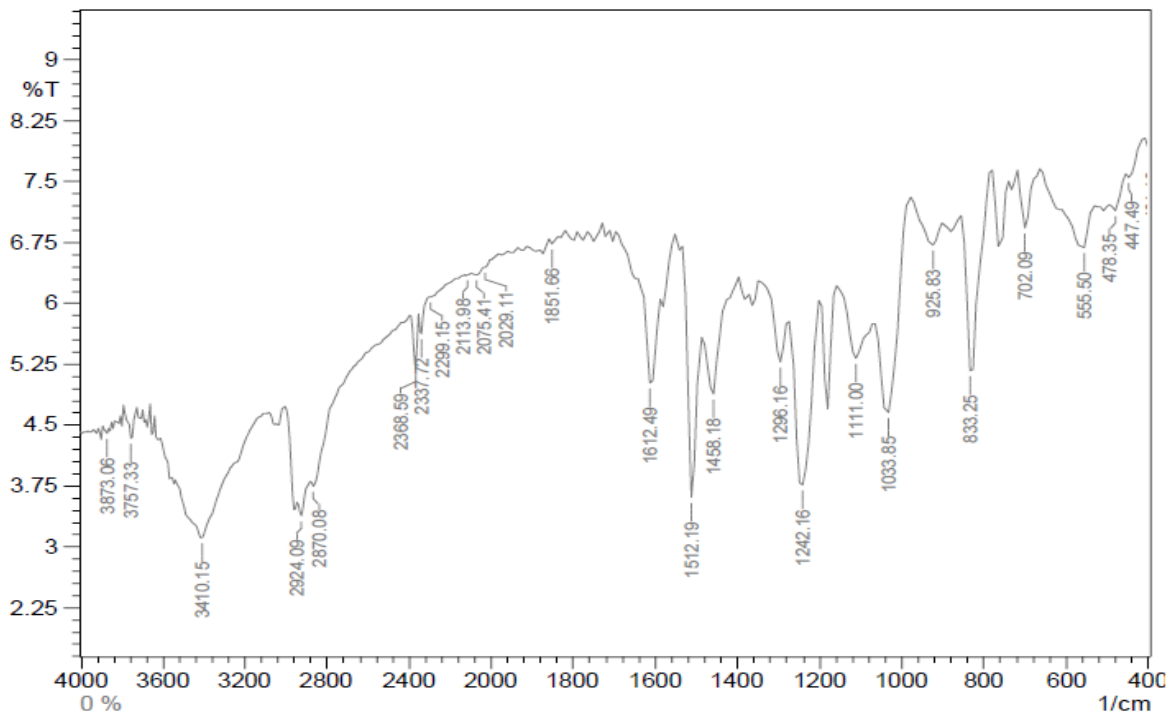


Figure 4-2 the FTIR Spectrum for (epoxy-polyol)

Table (4.1) The wavenumber of the bonds for epoxy

Band name	Wave length value (cm <sup>-1</sup> )
CH Symmetric & asymmetric stretch	3464 3417
Asymmetric CH stretch of CH <sub>2</sub> group	2924
Symmetric CH stretch of CH <sub>2</sub> group	2870
C-C vibration	1612 1512 1458
Asymmetric aromatic C-O stretch	1442
-C-O-C-	1111
Epoxy ring vibration	933 894
C-H out of plane	833

## 4.3 Mechanical Tests Result

### 4.3.1 Tensile Strength & Elastic Modulus

The results obtained from the tensile test indicate a decrease in tensile strength and Elastic Modulus when the percentage of polyol in the epoxy increases, and these results are normal, as the penetration of polyol between the chains of the epoxy structure leads to a slight freedom of movement of the chains, therefore their resistance to the force exerted in tensile strength, therefore the tensile strength and rigidity decreases as shown in figures 4.3 and 4.4. Alternatively, the cross-linking density of epoxy may be low due to the presence of polyols in the mixture, which reduces their density. Except for a small increase in one percentage, which is the 6%, which may be due to an increase in the percentage of polyol between the chains, filling the voids between chains, which served to restrict their movement.

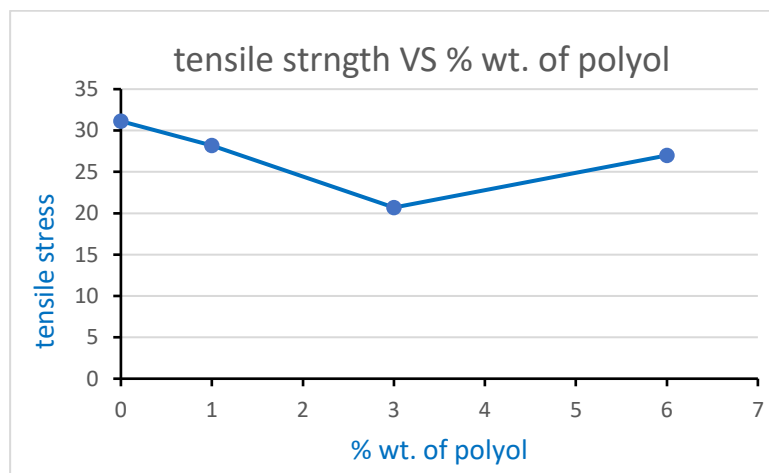


Figure (4-3) the scheme of tensile strength with the addition ratio of polyol

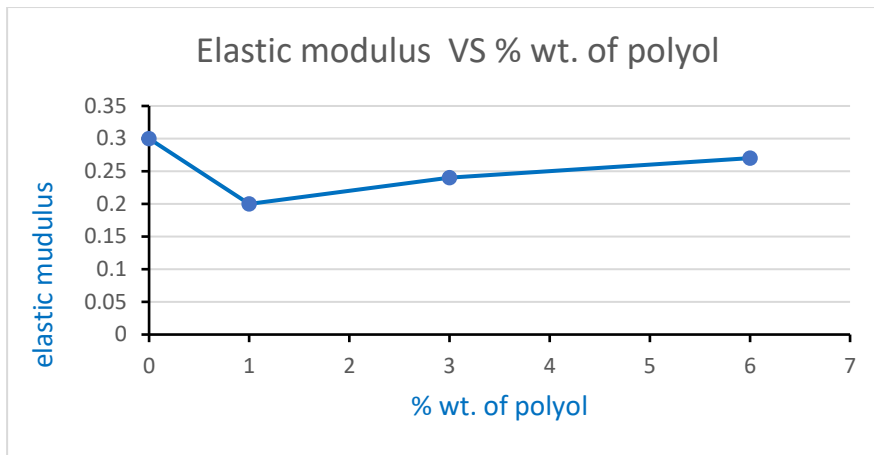


Figure (4-4) the scheme of tensile strength with the addition ratio of polyol

### 4.3.2 Impact

From the diagram in Figure 4.5, it is noted that the impact strength value increases slightly by increasing the addition ratio of polyols . That's due to the freedom of movement of the polymer network chains was improved or due to the lower density of the cross linking due to the addition of polyols to the mixture, which leads to increased toughness consequently improved impact strength. But in the last addition (6%), the lack of shock resistance is possible due to the presence of gaps or defects in the manufacture of samples for this test .

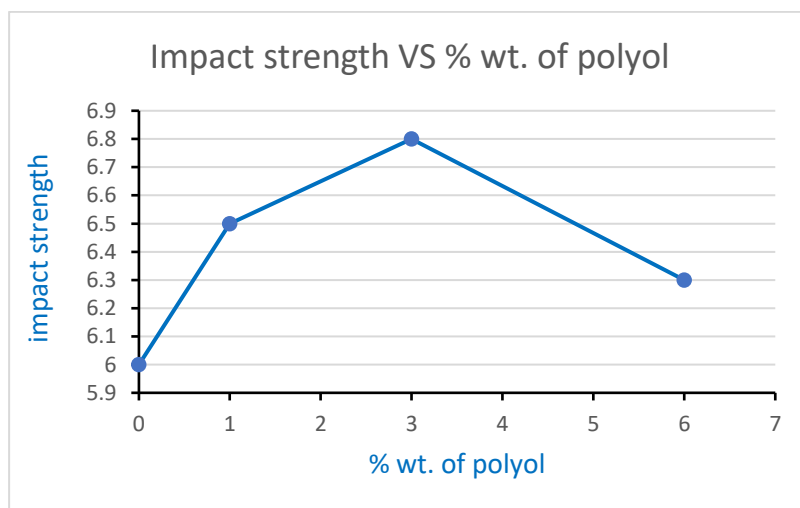
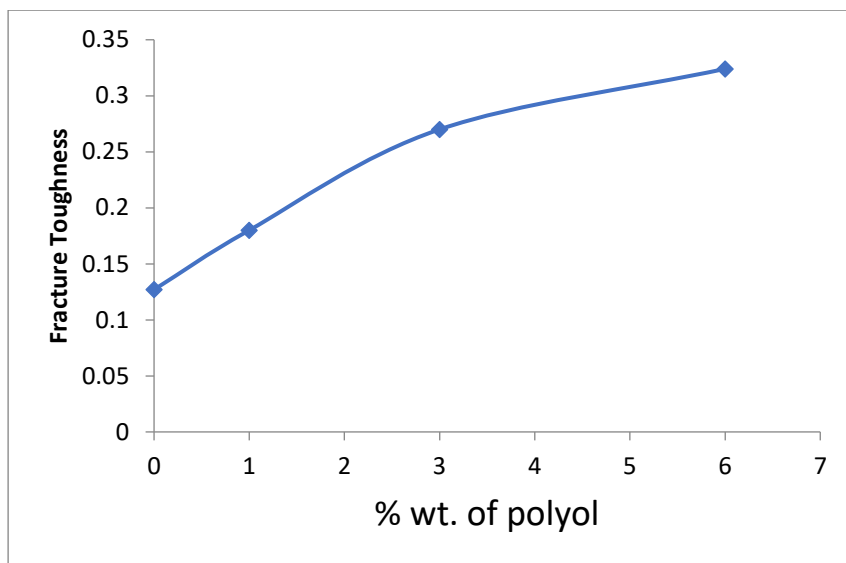


Figure (4-5) the scheme of impact strength with the addition ratio of polyol

### 4.3.3 Fracture Toughness

From figure 4.6 noted the fracture toughness was increase when add polyol from 1% wt. to 6% wt. That's mean fracture toughness is improving at addition. The improving in toughness due the addition polyol is permeate in epoxy structural midst cross linking of epoxy subsequently the density of cross linking is lower. As well the bonds length between the chains is longer. All that will lead to increasing the flexibility and toughness of the epoxy.



**Figure (4.6):fracture toughness of Epoxy-Polyol.**

### 4.3.4 Hardness

Using a Shore D Durometer, which measures a material's relative resistance to being indented while having a load applied to the indenter, the hardness of the samples is calculated.

The hardness in general reduced due to the decreased modulus of elasticity, that causes reduce surface hardness which causes the inspection needle to easily penetrate the sample that result from the presence of polyol which effect on the surface properties and thus the hardness decreases as show in Figure 4.7 .

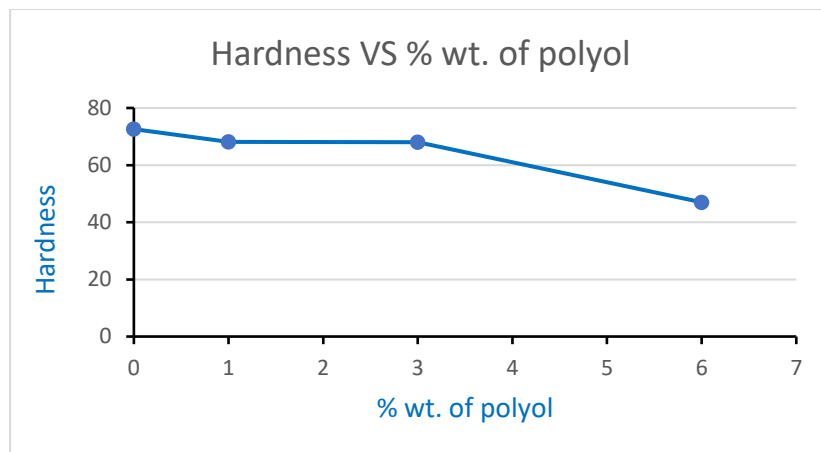


Figure (4-7) the scheme of hardness with the addition ratio of polyol

## Conclusions

From the results in chapter four it can be concluded the following:

1. Polyol addition does not form any interactions with epoxy as indicted FTIR analysis.
2. The increase in the polyol addition causes a reduction in mechanical properties (tensile strength, elastic modulus, and hardness), while causing an improvement in both fracture toughness and impact strength.

# Chapter five

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