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The Influence of Toughening Agents on The Mechanical Properties of Epoxy-Based Coatings

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Abstract

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

Keywords: Epoxy; Polyol; Fracture Toughness; Tensile strength; Impact strength.

1. Introduction

A polymer is a giant chemical compound composed of repeating units of identical or different monomers with or without loss of material [1]. 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 [2]. Epoxy resin is used in many applications due to its amorphous thermosetting material with an original hardness and strength. of unfortunately, cured epoxy systems have one major disadvantage: significant brittleness, poor crack resistance, and poor resistance to crack initiation and propagation[3],[4],[5]. 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 [6]. 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 [7]. Blending polymers can be an inexpensive method to develop materials with specific properties based on customer requirements [8]. 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 [9]. 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 [10]. 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 [11]. 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 [12]. Metals protected with epoxy are susceptible to wear and surface abrasion due to the complex network structure of pure epoxy that protects the metal [13],[14]. 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 very effective [15],[16]. Various researchers have attempted to increase the strength of the epoxy system using different cure modifiers[17] . 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[18].

This study will develop a mixture of epoxy and polyol, examining the influence of polyol content (1%, 3%, and 6% wt.) on mechanical properties. Tensile characteristics, impact resistance, and fracture toughness will be evaluated.

2. Materials and Methods

The components for this study included epoxy resin and polyol sourced from the polymers department laboratories, and the tests were conducted at the same department laboratories.

Table 1 shows the properties of the epoxy resin used.

Table 1: Properties of Epoxy resin

Property	Data
Chemical Base	Two-part epoxy resin. Part A: bisphenol F-(epichlorohydrin) Part B: ((izoforon diamine), (1-methylethyl)-1,1'-biphenyl)) (hardener)
Density	1.1 kg/l (at +20°C)
Compression strength	52 N/mm^2
Flexural Strength	61 N/mm^2

2.1. Sample Preparation

The first step: prepare the basic materials, which are epoxy resin, polyol additive. The addition ratio 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). When completing the weighing of the materials, put the epoxy resin, polyol, hardener additive according to the proportions in Table 1 in a glass container, and then mix the material in a mechanical mixer well for 10 min. After the mixing process, the mixture is placed in the vacuum remove for 10-15 min at room temperature, to remove the bubbles present on the surface of the mixture or inside the material. 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. For the curing process the prepared blend left for 24 hours. The table 2 below shows the addition of polyol to epoxy resin:

Table 2: the percentage of polyol and epoxy resin used.

Sample	wt.% of polyol	Epoxy (g)	Hardness(g)	Polyol (g)	polyol (g)/Epoxy
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

3. Characterization

3.1. FTIR Test

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 test was performed using FTIR instrument type IR Affinity-1 (made in Japan). The infrared spectrum was used within a range of (400–4000) cm-1.

3.2. Tensile Test

Universal testing machine wdw-5kN is utilized to perform the tensile behavior as per ASTM D-638 IV. Three specimens were examined with a speed of 5 mm/min and the mean value was considered.

3.3. Impact test

Impact test was performed according to ASTM D-256-87 by using GANT (HAMBURG) company (model WP 400 Charpy impact tester). Three samples were taken and the average value was considered.

3.4. Hardness test

Shore D hardness was measured for all samples according to ASTM D2240. Five reading after a specific time were taken for each sample and the average value was considered.

3.5. Fracture toughness

The fracture strength is measured according to international specifications with the previously used tensile device. ASTM D5045, as shown in Figure 1, 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.

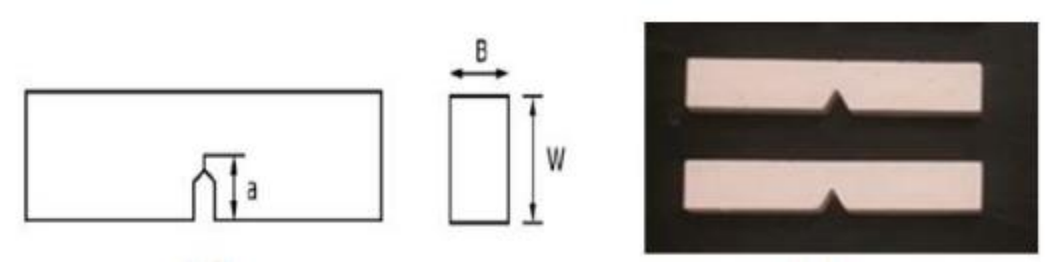

Figure 1: Fracture Toughness sample.

4. Results and discussion

4.1. FTIR analysis Results of Epoxy/Polyol Blend

The color change of the epoxy used in this study was observed from transparent white to dark while 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 2 and 3. It turned out from the two tests that there are 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 bands network as shown in table 3 [19].

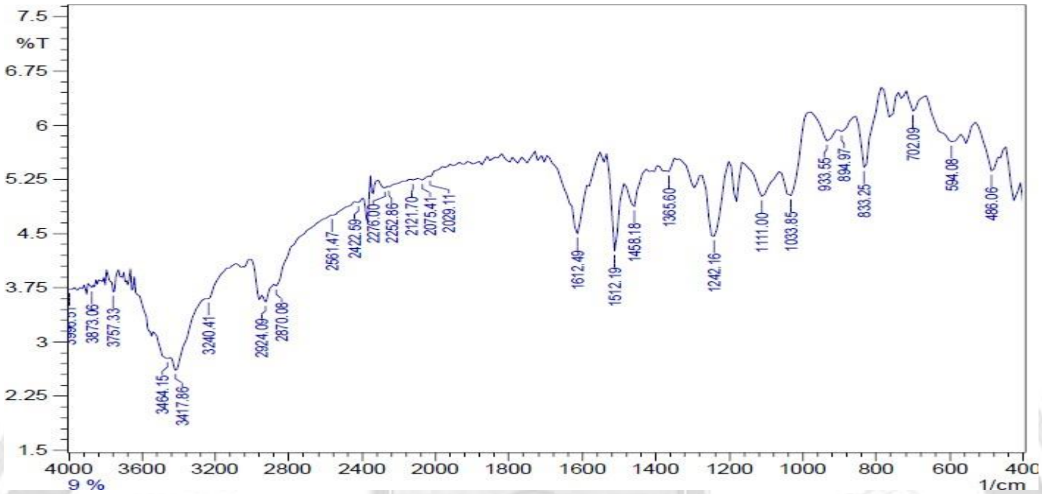

Figure 2: The FTIR Spectrum for epoxy

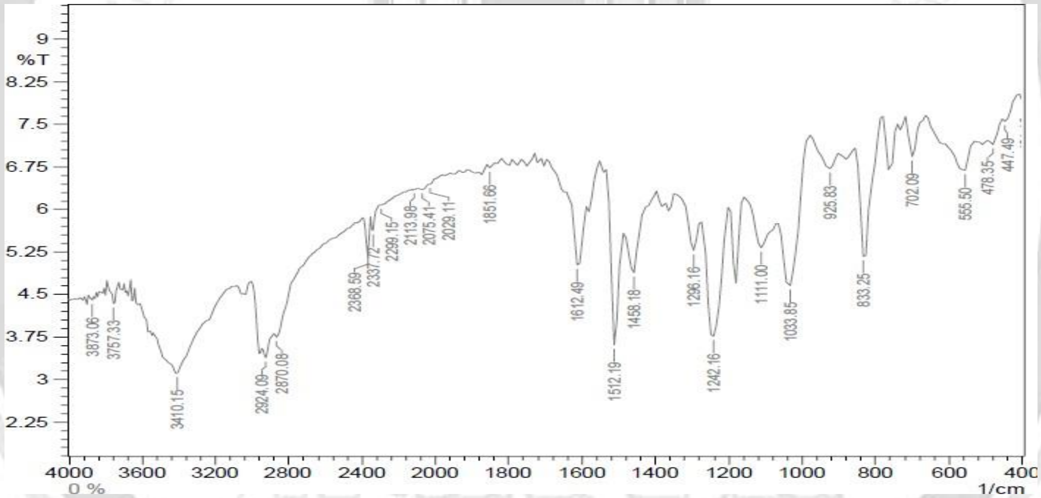

Figure 3: The FTIR Spectrum for (epoxy/polyol)

Table 3: IR bands of for epoxy

Band name	Wave length value (cm^{-1})
CH Symmetric & asymmetric stretch	3464,3417
Asymmetric CH stretch of CH_2 group	2924
Symmetric CH stretch of CH_2 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

4.2. Mechanical Tests Result

4.2.1. Tensile Properties

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. 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. Thus, the tensile strength and rigidity decreases as shown in Figure (4 and 5). 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 [20].

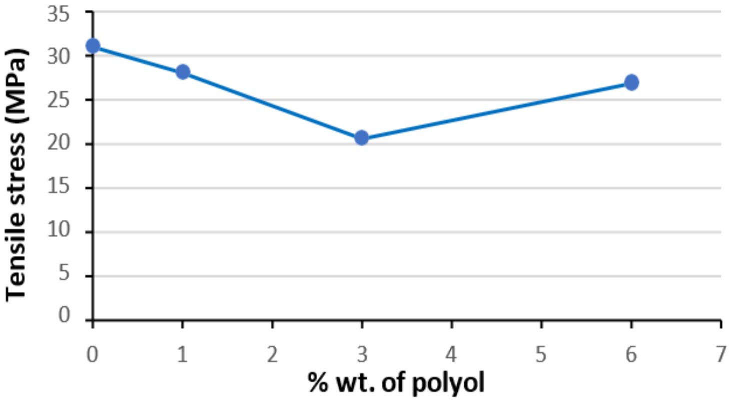

Figure 4: The tensile strength with the addition ratio of polyol

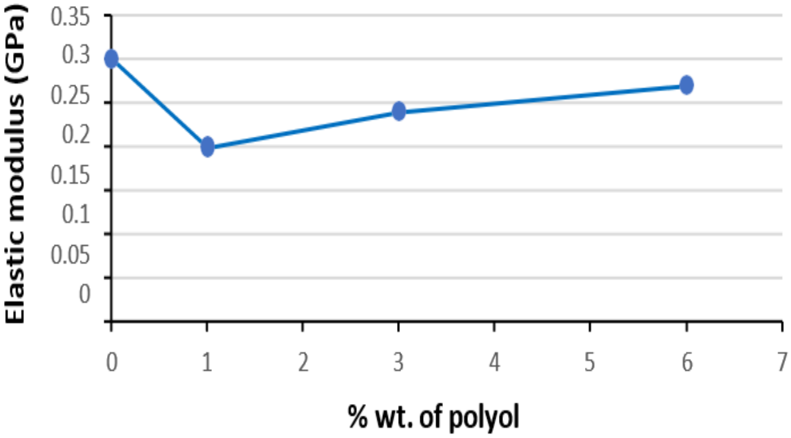

Figure 5: The tensile strength with the addition ratio of polyol

4.2.2. Impact Test Results

From Figure 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 [21].

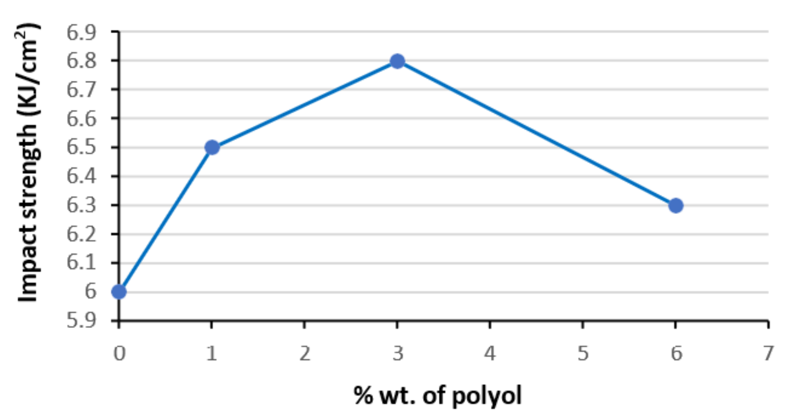

Figure 6: Impact strength with the addition ratio of polyol

4.2.3. Fracture Toughness

From Figure 7 it is noted that the fracture toughness was increase when add polyol from 1% wt. to 6% wt. That's mean fracture toughness is improving as polyol added . 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 [22].

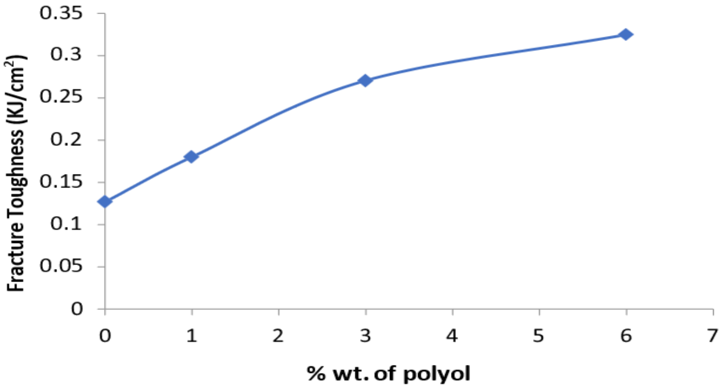

Figure 7: Fracture toughness of Epoxy-Polyol.

4.2.4. Hardness Test Results

Figure 8 shows the shore D hardness of polyol/epoxy blend. it is found that, the shore D hardness was decreased by the increasing polyol content, due to the reduction in tensile properties (modulus of elasticity), that reflected on hardness and causes reduction in 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 [20] .

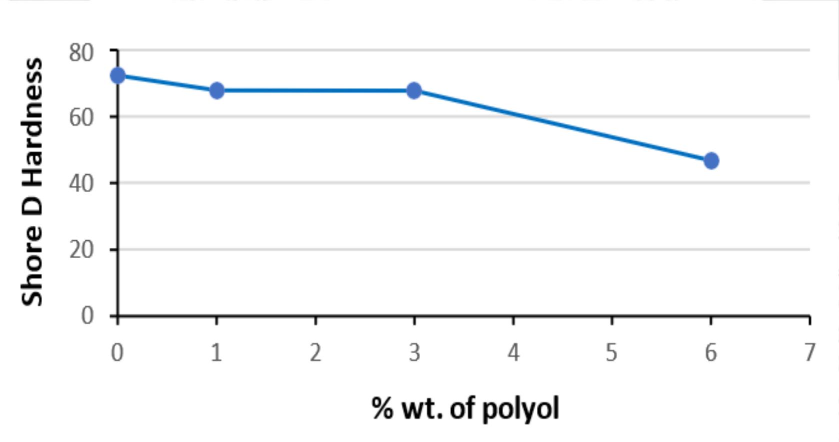

Figure 8: Shore D hardness with the addition ratio of polyol

Conclusions

From the above results it can be concluded the following:

1. Polyol addition does not form any interactions with epoxy as indicted by FTIR analysis results.
2. Both tensile properties (tensile strength, and elastic modulus) and Shore D Hardness were .decreased by polyol addition
3. Fracture toughness and impact strength were improved by the addition of polyol and it is .t and 6%wt for fracture toughnessfound that the best results at 3% wt. for impac

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تأثير عوامل التقوية على الخواص الميكانيكية للطلاءات القائمة على الإيبوكسي

أثير حسين مهدي

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الخلاصة

الايبوكسي هو احد انواع البوليمرات الأكثر استخداما على نطاق واسع في مجموعة متنوعة من التطبيقات بسبب بنيته الغير متبلورة مع صلادة و خواص ميكانيكية جيدة. ومع ذلك ، فإنه يعاني من صلادة وهشاشة عالية لذلك يجب تحسين مرونته وصلادته. في هذا العمل ، تم تحضير مزيج إيبوكسي/بوليول بكميات مختلفة من البوليول (1 ٪ و 3 ٪ و 6 ٪ بالوزن). تم تحضير الخلطات عن طريق خلط الإيبوكسي والبوليول والمصلب. تم استخدام التحليل الطيفي بالاشعة تحت الحمراء ومقاومة الشد ومقاومة الصدمة والصلادة ومتانة الكسر لتوصيف الخلطات. اظهرت النتائج أنه لا يوجد تغيير في منحنيات التحليل الطيفي بالاشعة تحت الحمراء. كذلك اظهرت نتائج الخواص الميكانيكية أن قوة الشد ومعامل المرونة والصلابة انخفضت مع إضافة البوليول. ووجد ان كلا من متانة الكسر ومقاومة الصدمة قد تحسنت مع إضافة البوليول..

الكلمات الدالة: إيبوكسي، بوليول، متانة الكسر، مقامة الشد، مقاومة الصدمة.