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"Study of Impregnation Process for Preparation of Short fiber Reinforced Epoxy Composites for Air Frame Structures

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Abstract

The Toughening system is very important mechanisms to improvement the toughness property of the brittle materials , such as thermosetting (epoxy , polyester) .

The good design of these toughened structure composite parts requires a detail understanding of the roles of these mechanisms within the base materials .

In the present study the epoxy matrix material is used to prepare toughening material by addition the rubber with two techniques (liquid and vulcanized powder).

Two analysis approaches are used in the study (theoretical and experimental) . Theoretically , micro&macro-mechanics models base on the FEM are used to study the effect of the additives on the matrix material.Two dimensional models are carried out and implemented by ANSYS 5.4 FE code . The first one to evaluate the effect of additives on Properties of the prepared material,and The second to evaluate the toughness of the materials by using crack opening displacement approach , and it is based on the properties which are resulted from the first model analysis.

. To verify the accuracy of these models in analysis , the experimental work is carried out to improve the epoxy toughness with the same techniques (addition of the rubber liquid and vulcanized powder) , also the short fibers (nylon 6/6) are used to strengthen the composites to keep the other properties of decreasing .

Different preparing samples are tested by mechanical and chemical testing within this work .

The results show that good agreement between the theoretical analysis and experimental , also show the low concentration of rubber additives(0 - 2.5%) improve the toughness without the effect on other properties .

High concentrations of rubber(5 – 10 %) require addition strengthened phase (short fiber) to improve the reduction in the other properties .

Chapter one

Theoretical part

1. 1 *Introduction*

A composite material can be defined as a combination of two or more materials that result in better properties than when the individual components are used alone. As opposed to metal alloys, each material retains its separate chemical, physical and mechanical properties. The two constituents are normally a (reinforced phase) and (matrix phase), matrices can be polymers, metals or ceramics. Composite materials are classified on the basis of the type of the matrix employed in them [1,2], .for example

1- Polymer matrix composite (PMCs).
2- Metal matrix composite (MMCs).
3- Ceramics matrix composite (CMCs).

Reinforcing phase includes many types such as fibers, particles, fillers, flakes, and laminates, composite materials can be classified according to these types of reinforcing materials as shown in fig (1-1) [3], which consists of three main divisions (particle reinforced, fiber,Reinforced and structural composites),also, at least two subdivisions exist for each [4].

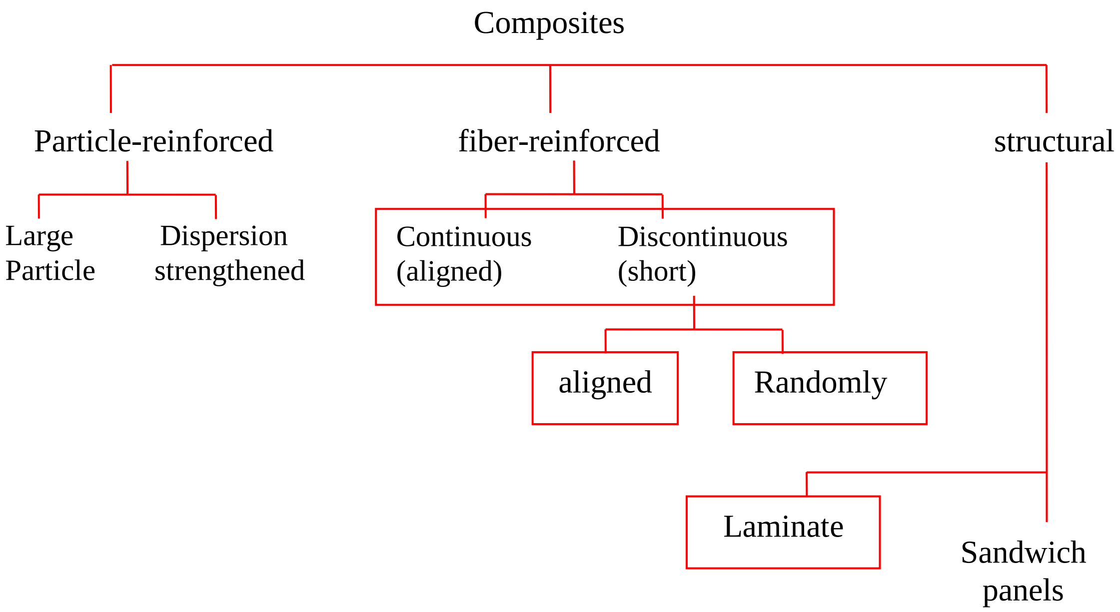


Fig (1-1) A classification scheme for the various composite types[5]

. Fibers may be continuous or discontinuous, these two types of fibers are sub classified as shown in fig (1-2) [1].

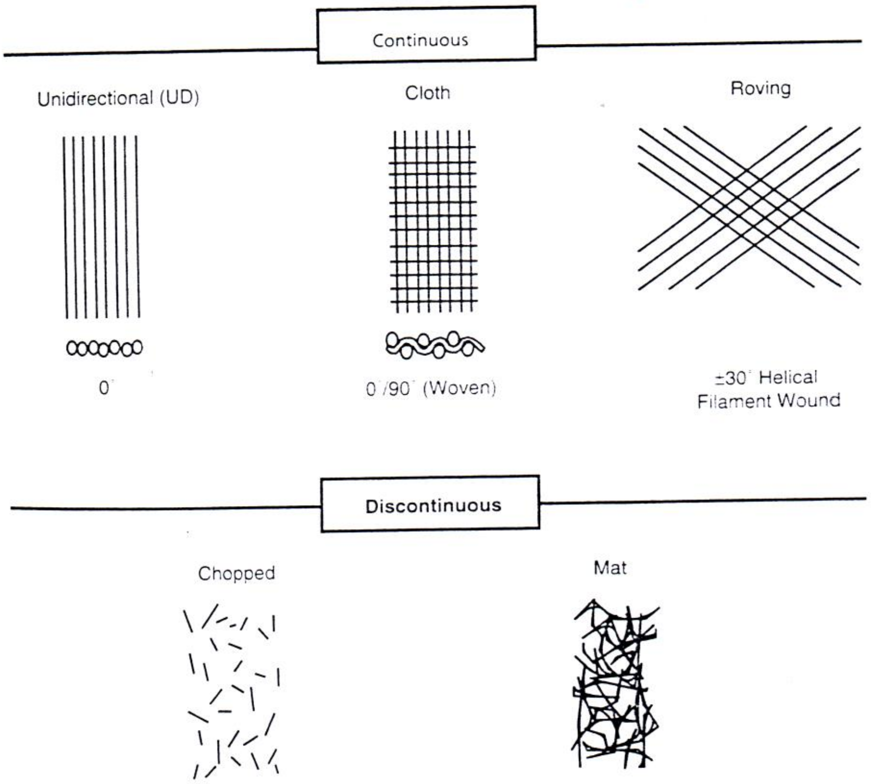


Fig (1-2) types of reinforced fibers [1]

Polymeric composites can be either Thermosets or thermoplastics. Thermoset resins usually consist of a resin (ex. including polyester, vinyl ester, epoxies, bismaleimides, cayanate ester, polyamides and phenolics,and others) [1, 5].

The Thermoset composite matrices have rigid structure and therefore; over the last 20 years extensive effort has been expended to develop resin systems that are Tougher and less susceptible to impact damage. Because of the progress science in the polymers industry, it can be obtain new polymers have desired properties by blending or alloying of polymers. Alloys (poly blends) and blends are combinations of polymers that are mechanically mixed. They do not depend on chemical bonding, but often require "compatibilizers". To keep the constituents from segregating [5, 6].

There are several types of blends classified according to physical cross-link such as interpenetrating polymer networks (IPNs) [7,8].

The IPNs used in military applications as aircraft, marine, cars, chemical industries, medical industries and electronic industries [9,10].

To impart greater toughness to the cross–linked Thermoset polymers , a number of different approaches have evolved single approaches as well as a combination of approaches are used to further enhance toughness. There is different toughening approaches [1] are-

(1) Net work alteration.

(2) Rubber elastomer second phase Toughening.

(3) Thermoplastic elastomer toughening.

(4) Interlayering.

1-2 *Epoxy Resins*

Epoxies are the most common matrix material for high performance composites and adhesives. Epoxies are the result of polymeric reactions with epichlorohydrin. The two most important plastics in this family are:

(1) The diglycidyle ether of bisphenol A (DGEBpA) and its homologs.

(2) The glycidyl ethers of various novolac resins.

The DGEBPA is the product of the reaction with bisphenol A (BPA) in the presence of an alkali and the glycidyl ethers are the products of reaction with the various phenolic novolacs.

The reaction to produce DGEBPA is shown in fig (1-3) while fig (1-4) illustrates the glycidel ethers of three novolacs.

The DGEBPA is the most widely used and it can range from a viscous liquid to a high molecular weight solid. Higher molecular weight homologs are produced by controlling the ratio of epichlorohydrin (glycidyle chloride) to BPA; the higher the BPA concentration during the reaction , the higher is the molecular weight. The glycidyle ethers of novolac resins provide higher temperature performance and improved chemical resistance than the BPA based epoxies. Their general properties include: toughness, less shrinkage curing, good weatherability, low moisture absorption, curing without the evolution of by-products, good wetting and adhesion to a wide variety of surfaces. Other excellent qualities are: good mechanical properties and thermal capabilities, excellent fatigue resistance, outstanding electrical properties from low to high temperatures, exceptional water resistance, practically resistance to fuels and general corrosion resistance. [1, 6, 11].

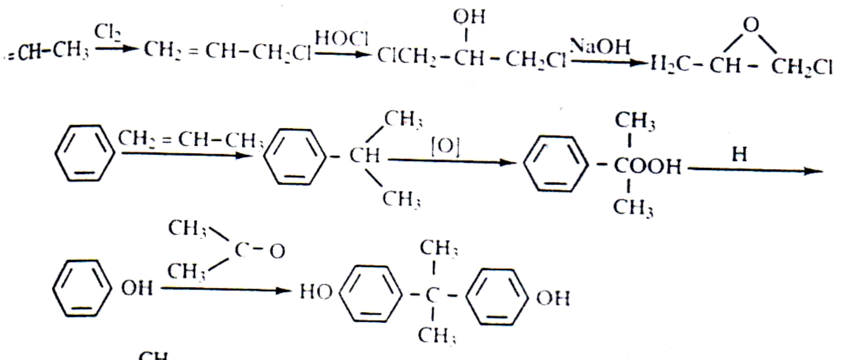


Fig (1-3) synthesis of diglycidyle ether of biphenyl A (DGEBPA) [6].

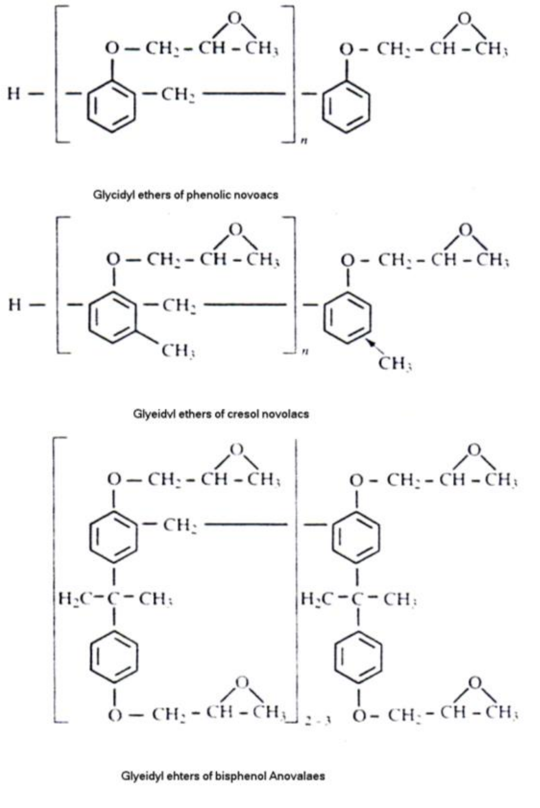


Fig (1-4) Glycidyle ethers (epoxies) of novolacs [6].

1.2.1 *Chemistry of the Epoxy Resin System*

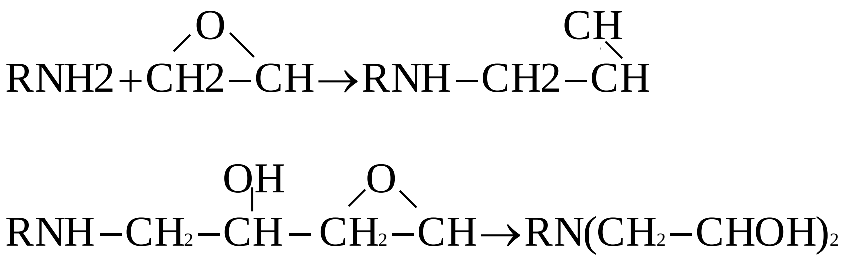
The major hardeners of epoxy resins are amines and hydrides. The chemistry of these hardeners / curative systems is:

O

Epoxy resin is characterized by the reaction of the epoxy group C —C known as the oxirane ring.

Polymerization reactions proceeded by the opening of the oxirane ring to form a difunctional chemical reacting species similar to unsaturated c=c group in polyether, epoxy resins are low–molecular weight polymers containing oxirane rings at each end of the chain. They are cured by adding a multifunctional chemical to the mixture that serves to cross – link the system by an addition reaction with the oxirane ring. The most common cross – linking agents for epoxies are amines[12].

The basic reaction between (primary) amine and the epoxy group as following:



$$RNH2+\overset{O}{CH2-CH}\rightarrow RNH-CH2-\overset{CH}{CH}$$

$$RNH-CH_2-\overset{OH}{CH}-\overset{O}{CH_2-CH}\rightarrow RN(CH_2-CHOH)_2$$

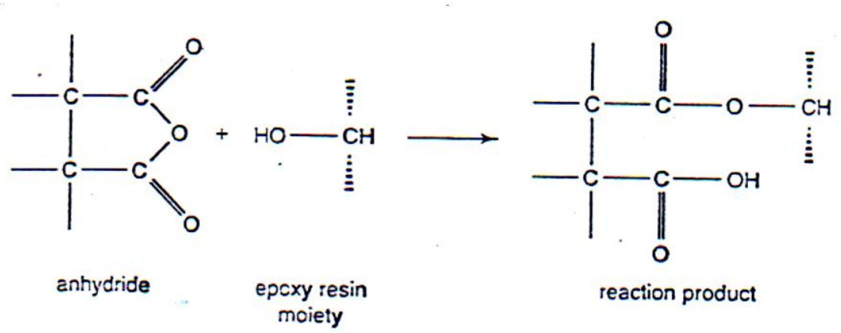
As shown, each of the two hydrogen atoms of the primary amine, RNH_2 where R is a generic unspecified organic grouping, is capable of reacting of epoxide group. During the latter stages of the reaction, the resultant OH groups that are formed in the amine reaction can also react with epoxy groups and further increase the cross – link density of the polymer[13].

One advantage of amine – cured epoxy resin is that they can harden or cure at a room temperature. However, a room temperature curing leads to polymers with a low temperature stability. In addition, the moisture resistance of these epoxy resins is generally low. Both temperature and moisture resistance can be improved by post curing the resins above 212°F (100 °C).

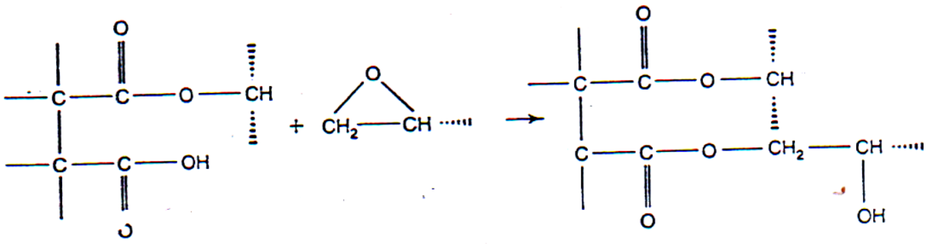
Here, the chemical cross–links of the resin are maximized as complete reaction of all epoxy groups is approached.

The reaction of an hydride curing agents with epoxy resins is more complex than that of amine cures. During reaction, several competing reactions can take place. The most important reaction are as follows:

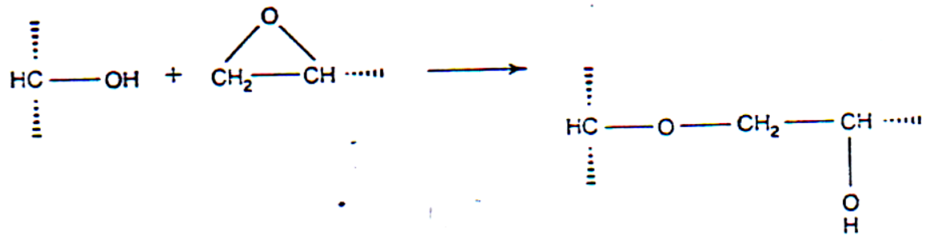
1. Opening of the an hydride ring with OH groups from the catalytically reacted epoxy groups to form a carboxyl group:



2. Subsequent reaction of the carboxyl group with the epoxy group.



3. Epoxy groups in turn, reacting with the formed OH groups:



Compared to amine cures, the pot life of an hydride cures in long , and the reaction produces allow exothermic. Long – time, elevated – temperature cures up to 392 °F (200 °C) an hydride cures result in much better chemical resistance for the final cured resin product . [1, 12, 13].

The selection of an appropriate curing agent is as important as selecting the proper epoxy resin. The type of curing agent will determine the rate of reactivity, degree of exothermic, formulation viscosity, gel time, and the heat requirement during the cure cycle. In addition, application technique, pot – life – requirements, and the desired performance properties of the cured product must be considered when selecting an epoxy curative. Curing agents determine the type of chemical bonds formed and the degree of cross – linking, which occur with the epoxy resin. [14].

1.2 .2 *Curing of Epoxy Composite*

The thermal portion of a classic cure cycle for a (350 F°(176.6C°) curing Thermo set epoxy part is shown schematically in fig (1-5) it contains two ramps and two isothermal holds. The first ramp and isothermal hold usually in the range of (240 F° (115.5C°)) – (250 F° (121.1C°), is used to allow the resin to flow (bleed) and volatiles to escape[1].

The imposed viscosity curve in the figure shows that the semi–solid resin matrix melts on heating and experiences a dramatic drop in viscosity.

The second ramp and hold is the polymerization portion of the cure cycle. During this portion, the resin viscosity initially drops slightly due to the application of additional heat and then rises dramatically as the kinetics of the resin start the cross – linking process[1].

The resin gels into a solid and the cross – linking process continues during the second isothermal hold, usually at (340 °F (171.1°C)) – (370 °F (187.7°C)) for epoxy resin systems. The resin is held at this cure temperature for normally 4-6 hr, allowing time for the cross – linking process to be completed. It should be noted that as the industry has moved towards net resin content systems, the use of the first isothermal hold which allows time for resin bleeding has been eliminated by many manufactures resulting in a straight ramp – up to the curing temperature as illustrated in fig (1-6) [1].

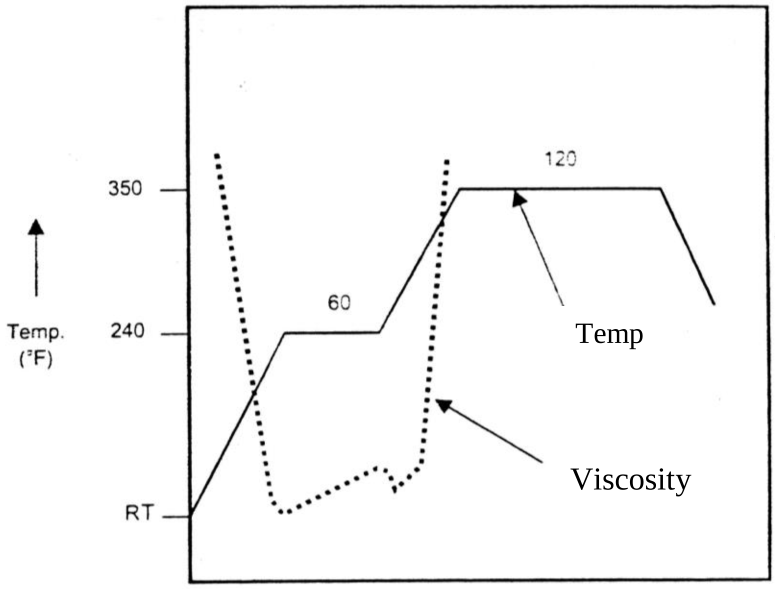


Fig (1-5) Typical Composite Thermal Cure profile [1].

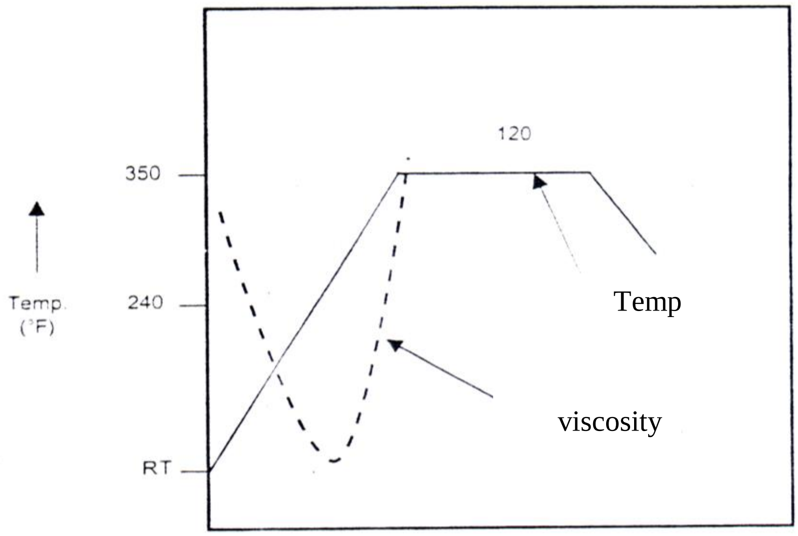


Fig (1-6) Straight ramp – up Cure Cycle [1].

The curing resin system will undergo several stages:

1) Liquid / Fluid
2) Gel stage
3) Rubbery stage

4) Tough / glassy solid

Depending upon the processing temperature, the liquid – to – gel – to – rubber transition may occur from hours (for room temperature cures). To minutes, to seconds[15].

The gel point in a thermosetting resin system is the point in the cure – time sequence when the resin undergoes a sharp rise in viscosity and ceases to be a fluid. Theoretically, the gel point is defined as the time in the cure when each polymer molecule in the system is tied together by at least one cross – link. Therefore, at the gel point, the polymer molecules in the resin system have combined and have reached an infinite molecular weight. After the gel point, the number of cross – links in the polymer system continues, the cross – link network gets tighter and tighter, and resin becomes a solid. it is at the gel stage that the influence of cross – linking takes hold. The rubbery stage is intermediate in cross – linking[15].

In the solid glassy state of the resin, the ultimate number of cross – links in the resin system exists, fig (1- 7).

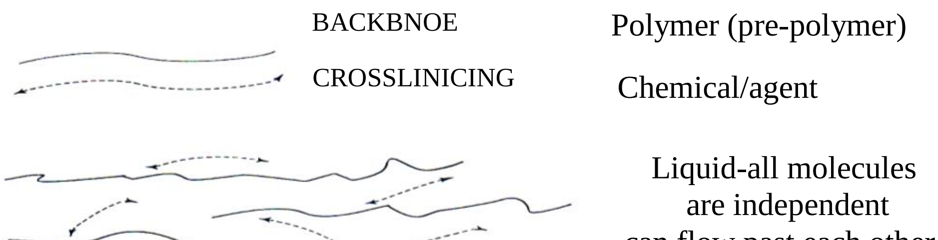


Fig (1-7) Nature of Molecules at various stages of thermosetting resin cure [9].

The cured resin will achieve its maximum strength, durability, chemical resistance and stability [15].

After the resin gels and forms a rubbery solid, it cannot be re-melted, further heating causes additional cross – linking until the resin is fully cured.

13. Toughening Approaches

The toughness limitation of Thermoset matrix is a direct result of its rigid. Highly cross–linked. Glassy polymer structures that form during cure. These rigid structures have both advantages and disadvantages. The main advantages are high-temperature capability and the ability of the rigid matrix to stabilize the reinforcing fibers during compression loading. The greatest disadvantage is their susceptibility to delimitations when impacted of particular concern is low velocity impacts causing internal eliminations that cannot be detected during visual walk – around inspeetions. [1]

Like wise, compared to the stiff Thermoset systems both have a some what lower resin modulus and therefore; exhibit some what lower compression strengths. Although certainly not true in every case, the tougher systems generally have less heat resistance than the rigid glass Thermosets. [1]

Cross – links are the chemical ties between two or more polymer chains that give the cured polymer its strength, the rigidity and thermal resistance. As shown in fig (1-8), the higher the cross – link density (i.e number of cross – links per unit volume) and the shorter the polymer chain length between the length between the cross – links, the more constrained is the chain motion and thus the stiffer and more thermally resistant is the molecular structure.

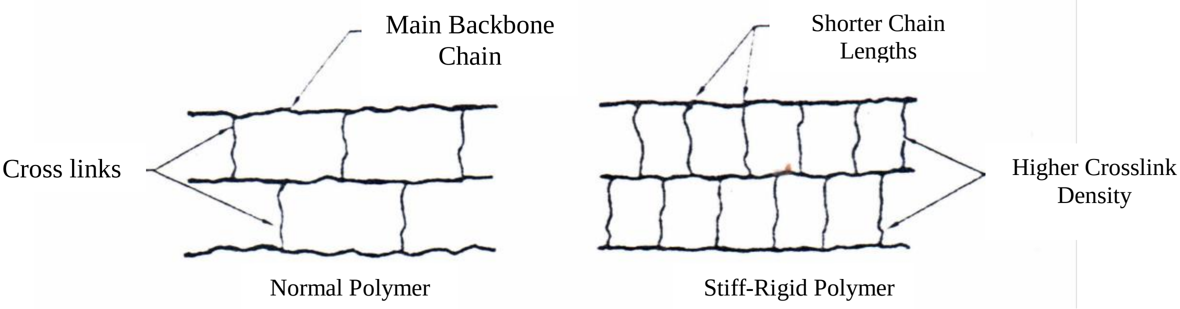


Fig (1-8) Effect of Crosslink Density on Rigidity [1].

Further stiffing can be imparted by the use of stiffener backbones in the main chains. however, this rigidity results in brittleness, low strain – to – failure and poor impact and post – impact properties highly cross – linked rigid structures usually exhibit good thermal stability due to their ability to restrict the relative motion of the polymer chains by the chemical bonds holding them together since the cross – link bonds are primary covalent bonds, they retain a large portion of their strength as the temperature is increased. When the cross – link density is high and the bond lengths are short, acceptable properties are maintained up to near the Tg of the resin.

Above the glass transition temperature, the rigid solid polymer converts to a softer rubber – link material as the main backbone chains. Themselves soften. Therefore, highly cross-linked polymers possess moderate to high strength and stiffness and excellent temperature resistance[1,16].

The molecular structure of a Thermosetting polymer determines how it processes and its resultant properties. example of properties that are a function of molecular structure include glass transition temperature , moisture absorption strength , modulus , elongation and toughness. By altering the molecular structure. It is possible to alter these performance properties. The molecular structure is controlled by its backbone structure (i.e. the main polymer chains) and its network structure (i.e the number and types of cross – links) the chemical structure of the main monomer defines the backbone structure and to some extent the network structure.

The network structure is also influenced by the type of curing agent or the hardener used in the curing reaction[1,16].

To impart greater toughness to the cross – linked Thermoset polymers a number of different approaches have evolved, four toughening approaches will be discussed:

1.3.1 *Network Alteration*

Since the brittleness of the Thermosetting polymers is a direct consequence of their high cross – link densities. One method of toughening a Thermoset polymer is to lower the cross – link density. This approach, when taken to the extreme case where there are no more cross – links, results in a Thermoplastic polymers. since amorphous the Thermoplastic polymers are inherently tough. The decrease in cross –

link density is also accompanied by a decrease in a desirable properties such as glass transition temperature and resin modulus.

There are two well – known methods for reducing the cross – link density of Thermoset polymers:

- The First method: includes altering the main monomer backbone chain by increasing the molecular weight between cross-links with long chain monomers as shown schematically in fig (1-9). The resulting decreasing in the glass transition temperature can be somewhat off set by constructing along – chain monomer which is very rigid and contains bulking side groups. The decreased mobility of the polymer chains will some what compensate for the loss in the glass transition temperature due to the lower cross – link density[1,17].

Second method: is to lower the monomer functionality. Most highly cross – linked Thermosetting polymers have a functionality of four, which

- The means that there are four reaction end – groups that can react and cross – link during cure as shown in fig (1-10), if a portion of the polymer mix contains a monomer with a functionality of two, there are less available sites for cross – linking during cure and the toughness will, therefore; be improved due to the lower cross – link density. However the heat resistance is again affected as evidenced by the lower glass transition temperatures of difunctional monomers[1,13,14].
- The Third method: this is method frequently used to improve incorporate flexible sub groups into the main chain backbone of either the resin or the curing agent. Although depicted as "springs" in fig (1-11).more flexible aliphatic segments are used in

preference to the more rigid and bulky aromatic groups that contain the large benzene ring.

As with the other approaches desired above , there is a trade – off in the glass transition temperature , this can be minimized by using some stiff segments along with the flexible one[1].

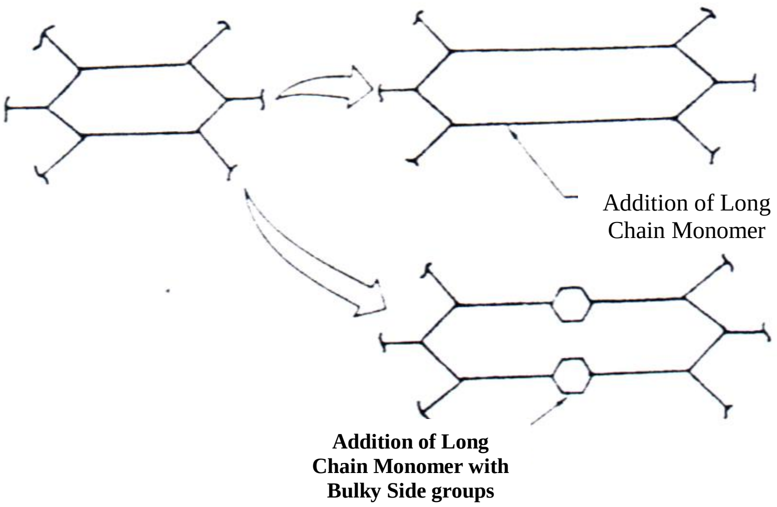


Fig (1-9) reducing Cross–Link Density with long chain Monomers [1].

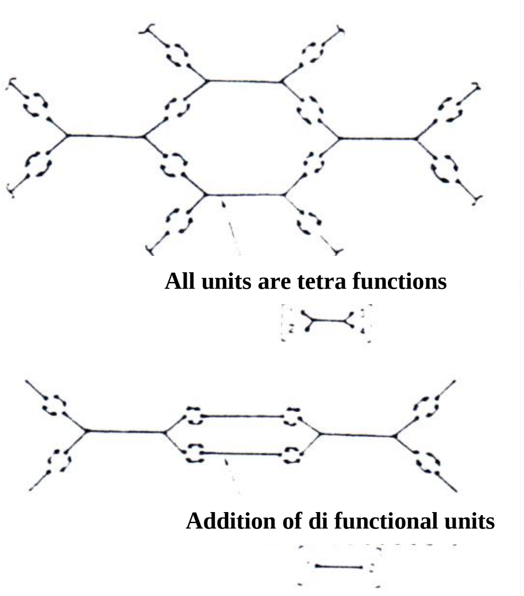
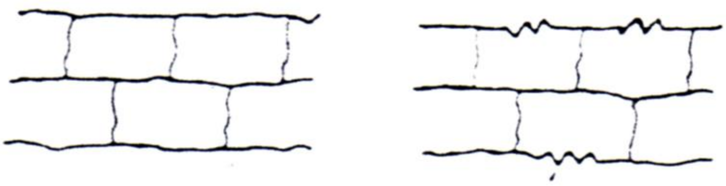


Fig (1-10) Effect of monomer functionality on cross – link Density [1].



Flexes Subgroups

Fig (1-11) Toughening with Flexible subgroups [1].

1.3.2 *Rubber Elastomer Second – Phase Toughening*

When a crack initiates in a brittle glassy solid, it requires very little energy to propagate. In fiber reinforced composite , the fibers will prevent in – plane crack growth. However, if the crack is inter laminar (i.e. between the plies). The fibers are of no help in preventing crack propagation. One way of reducing crack propagation is to use second – phase elastomers. Discrete rubber particles help to blunt crack growth by promoting greater plastic flow at the crack tip as shown in fig (1-12)[1,17].

The size of the ealstomeric domains is a critical factor in determining the micro deformation processes that control toughening Rubber particles, usually round , having domain diameters of 100 – 1,000 A° initial shear yielding while larger domains (10,000 – 20,000 A°) are generally believed to lead to crazing. Since matrix crazing is not possible in highly cross – linked systems due to their low tensile elongations, very small domains are used to enhance the shear deformation processes. However is the cross – link density permits the use of larger domain sizes. Bimodal distributions (i.e. a matrix of large and small domains) of the elastomer will result in both crazing and shear. Since these mechanisms complement each other, the toughening effect can be nearly doubled[1,16,17].

A finely dispersed phase of elastomer–rich domains can be obtained by using either preformed rubber particles or a rubber elastomer system that is initially soluble in the liquid resin, but then the phase separates (i.e. precipitates) during cure performed particles are advantageous because they can be used as additives or fillers. Also, their domain size is easier to control than when a phase separation process is used[18].

Unfortunately, commercially available preformed rubber particles are suitable only for toughening some of the lower–temperature Thermosets. When elastomer domains are to be formed during cure, it is necessary to use a rubber with suitable solubility. The rubber must initially be soluble in the resin and then separate into the desired small domain during the curing process. An elastomer that is too soluble will remain in solution too far into cure and significant quantities will be trapped in solution when the resin gels. The trapped elastomer will then act as a plasticizer and subsequently lower the glass transition temperature and hot – wet properties. On the other hand, if the elastomer is not be soluble enough, a stable solution with the resin will not be possible and a fine dispersion of particles will not be obtained. If just the right amount of compatibility exists, then the elastomer will initially remain in solution and once the resin begins to cure , small particles will uniformly precipitation into the resin matrix. Early and complete phase separation is necessary to maintain good hot – wet matrix performance[1].

The elastomer itself must have good rubber characteristics. Specifically, the elastomer – rich domain must have a Tg lower than about – 100 F° (-73.3 °C). So that when a crack travels rapidly though the materials. The domain still acts as elastomers. If the Tg is too high (i.e. too close to room temperature). Then at high deformation rates it will behave like a glass and the desired toughening effect will not be achieved. Another requirement is that the elastomer must thermally and thermally – oxidatively stable, If unstable rubbers are used, they are likely to across – link or degrade when oxidized , which would embrittle the elastomeric domains[1,17].

Elastomeric second - phase toughening is not always effective. If the resin is too highly cross – linked, then the resin lacks the ability to deform locally. In the absence of some localized deformation, the addition of an elastomeric second phase is largely ineffective , as the cross – link density is lowered , the benefits of second – phase elastomeric toughening rapidly increase , in epoxy resins. It has been shown that the relatively small gains in toughness obtained by modification of the monomer stiffness or length , or by altering the network structure can be greatly amplified by the use of second – phase toughening[1].

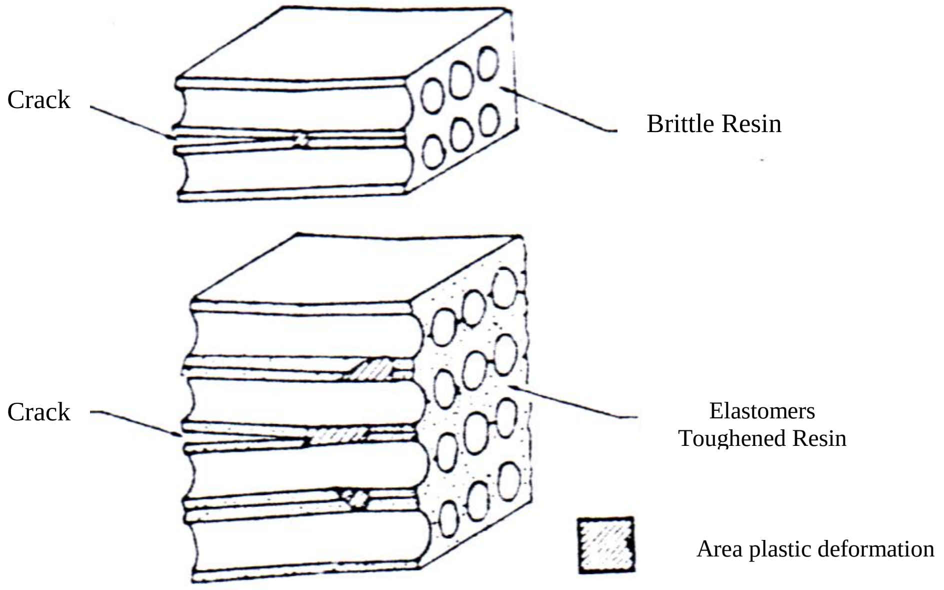


Fig (1-12) interlaminar crack propagation in composite laminates [1].

1.3.2.1 Toughening mechanisms in rubber – toughened epoxies

They include:-

1. Localized shear banding or shear yielding in the epoxy matrix between rubber particles.
2. Rubber particle cavitations that initiates plastic void growth in the epoxy matrix.
3. Rubber – Bridging or rubber – tear mechanism.

A schematic of each of the three toughening mechanisms can be seen in fig (1-13). The overall toughening, ψ, may be represented by[18]:

$$\psi = \Delta Gs + \Delta G\upsilon + \Delta Gr \qquad \text{equ (1-1)}$$

Where ΔGs, ΔGυ and ΔGr represent the toughening contributions due to shear banding, plastic void growth, and rubber – bridging mechanisms, respectively. The overall toughening can be related to the fracture energy G_{1c} as[18]:

$$G_{1c} = G_{1cu} + \psi \qquad \text{equ (1-2)}$$

Where G_{1cu} is the fracture energy of the unmodified epoxy. Through a lengthy process, the following set of equations are derived

$$\Delta G_s = 0.5\left(1+\left(\mu m \big/ 3^{1/2}\right)\right)^2 \left[(4\pi/3Vf)^{1/3} - 54/35\right](V_f\ \sigma_{yc}\gamma_f\ r_{yu}\ K_{vm}^2) \ \dots\dots\dots equ\,(1-3a)$$

$$\Delta G_v = \left[1 - (\mu m)^2 \big/ 3\right]\left[(V_{fv} + V_{f_r})(\sigma_{yc}\ r_{yu}\ K_{vm}^2)\right] \qquad \text{equ (1-3b)}$$

$$\Delta G_r = \Gamma_t\,(T)V_{f_r} \qquad \text{equ (1-3c)}$$

Substitution of equations (1-3) a-c into equations (1-1)

$$\psi = 0.5\left(1+\left(\mu m \big/ 3^{1/2}\right)\right)^2 \left[(4\pi/3V_f)^{1/3} - 54/35\right](V_f\ \sigma_{yc}\gamma_f\ \ K_{vm}^2)$$
$$+\left[1 - (\mu m)^2 \big/ 3\right]\left[(V_{fv} + V_{f\ r})(\sigma_{yc}\ r_{yu}\ K_{vm}^2)\right] \qquad \text{equ (1-4)}$$

μ_m: material constant

V_f: equals V_{fr} or V_{fv} depending on weather there has been any void growth.

σ_{yc}: compressive yield stress of the matrix material

γ_f: shear fracture strain of the matrix epoxy

r_{yu} : plastic zone radii for unmodified epoxy

K_{vm}: maximum stress intensity factor.

$V_{f\upsilon}$: volume fraction of voids

V_{fr}: initial volume fraction of rubber particles

$\Gamma_{t(T)}$: Tearing energy at room temperature

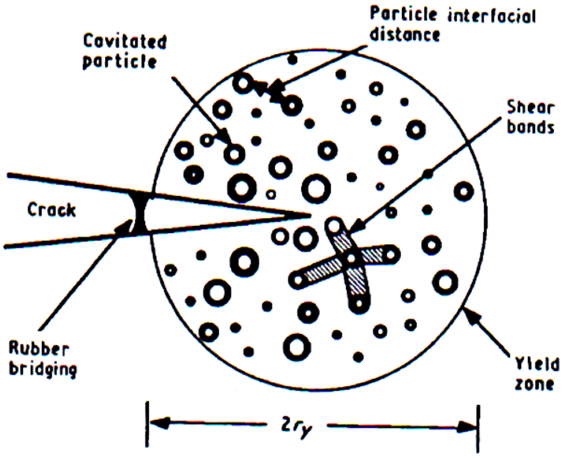


Fig (1-13) schematic of three toughening mechanisms in rubber – toughened epoxies [18].

This model indicates that approximately 50 percent of the energy dissipation occurs through shear yielding indicating that it is the primary toughening mechanism. This model also shows that rubber – bridging plays only a minor role except at low-test temperatures[18].

1.3.3 *Thermoplastic Elastomeric Toughening*

A number of important commercially available toughened Thermoset composite systems are based on the thermoplastic toughening.

Thermoplastic toughening can exhibit four distinct morphologies in the cured composite:

1. Homogeneous (single phase).
2. Particulate (thermoplastic particles in a continuous Thermoset matrix).
3. Co–continuous (both the thermoplastic and Thermoset are continuous).
4. Phase inverted (The Thermoplastic is continuous and the Thermoset is discontinuous).

It has been shown that the co – continuous morphology results in the greatest toughness improvement.

Polyetherimide (PEI), polyethersulfone and polysulfone (PS) have all evaluated. In a co–continuous structure, the thermoplastic increases the toughness while the cross – linked Thermoset helps to retain a high glass transition temperature and hot – wet performance. A thermoplastic with a high Tg helps to maintain the final Tg, since the Tg is at least the average of the separate compenents. The selection of the optimum thermoplastic component depends on its compatibility, heat resistance and thermal stability. Chemical compatibility is required so that the thermoplastic with remain in solution (i.e. not phase separate) until the Thermoset network has gelled[1,17].

In addition, the viscosity of the ungelled resin must be controlled so that it remains low enough to allow fiber wetting and ply bonding during cure.

Finally, the thermoplastic must have good heat resistance and be thermally stable to maintain hot – wet performance.

1.3.4 . ***Interlayering***

A "mechanical" or "engineered" approach to toughness can be achieved by incorporated a thin layer of a tough ductile resin between the individual prepreg plies

As shown in fig (1-14) this layer is usually thin (0.001 inches or less) and must remain fairly discrete during the composite curing operation. The rationale behind this approach is that the stiff brittle matrix supports the carbon fibers in compression and thus helps to maintain the hot – wet performance , while the tough interlayers provide the desired increase in resistance to low – velocity impact . since the tough interlayer has a high starin – to – failure , it helps to reduce the interlaminar shear and normal forces that can induce delaminations. The original development work was conducted using tough film adhesives that were simply placed between the preprege plies during lay – up[1,16].

More recently, discrete thermoplastic toughening particles have been added to the surfaces during the prepregging operation. The particles one layer than the fiber and , therefore; remain on the interlayers during prepregging and cure. The interlayering approach can be used with either brittle or toughened resin systems. Although a toughened resin system used in combination with interlayers provides better impact resistance[1,16].

The hot – wet compression strength decreases some what as compared to using a stiff brittle matrix by itself.

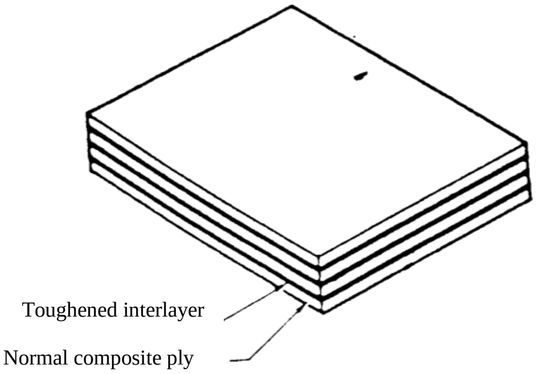


Fig (1-14) Toughening Interlayering [1].

1.4 *Fabrication of Reinforced plastics*

The various Fabrication processes may be grouped into :-

1- contact molding methods (as in hand lay – up, spray up, vacumbag, pressure bag, autoclave, etc….).

2- matched mold methods (as in compression molding, transfer molding, compression injection molding, stamping, etc).

3- other methods (as in filament winding, cold press molding, pultrusion, continuous lamination, centrifugal casting encapsulation, rotational molding, reaction ingction molding, etc). they are used with continuous fiber reinforced plastics **[6].**

the hand lay- up is disscused which used in this work

1.4.1 *Hand lay –up*

Hand lay – up is the oldest and in many ways the simplest and most versatile process, but it is very slow and labor intensive. It is suited fromaking large, high strength parts at low to medium volumes [19]. (Abombination of reinforcement in roll form is laid into an open mold and impregnated with resin as shown in fig (1-15). It consists essentially of the hand – tailoring and placing of layers of (usually glass, nylon) fiber mat fabric, or both on a one – piece mold and simultaneously saturating the lagers with aliquid resin (commonly poly esters, epoxy). The assemblage is cured, with or without heat , and usually with no pressure . Alternatively, a preimpregnated sheet (a pre – preg) with partially cured dry material such as sheet – molding compound (SMC) may be used, but in this case heat is applied and with good probability , low pressures will be applied [6].

In this process components are normally produced on a mole mould coated with a suitable release a gent which is usually liquid poly (vinyl acetate) (PVA) or liquid wax, although poly (tetrafluoroethane) (PTFE) / silicone sprays or polyesters films are sometimes used .

The brush or roller is used for impregnation, it should be worked will astippling action and not moved side ways a cross the suface. The normal brushing a ction will displace the fibers and distribute them unevenly . The paddle and ribbed rollers have proued to be particularly in the resin [20].

The principal advantages of hand – lay processes are versatility, there is liltle limitation on the size and complexity of the moulding, and low capital cost the only significant invest ment being that of tooling [11].

The major disadvantages of the technique are low fiber volume fractions and hence low mechaincal properties , typical values are 20 -30 % depending on the type of the reinforcement [11].

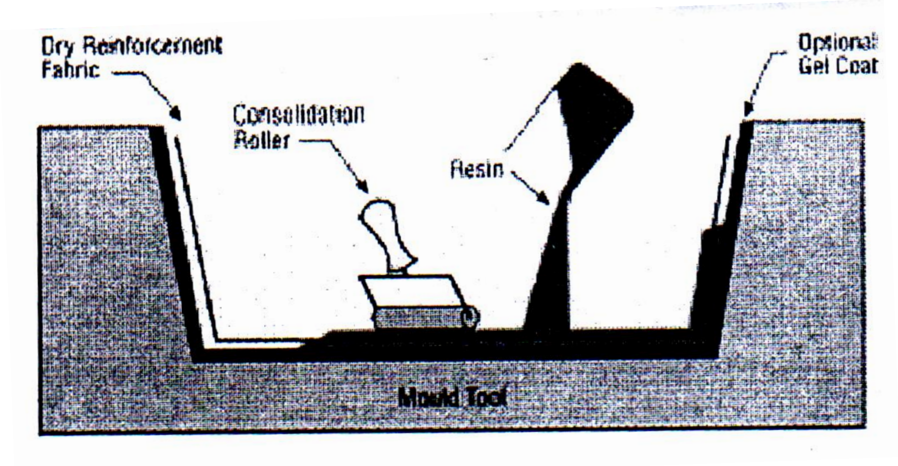


Fig (1-15) hand lay – up [20].

1.5 Mechanical Properties

The important consideration to limit the usages of polymer materials are the mechanical behaviors knowledge included by the applied stress, which may be possible to be stationary or mobile. Each type of the polymer materials characterizes by definite properties differs from other this is due to presence of two kinds of bonds, The chemical bonds between the chain atoms and the Vander Waals bond between polymer chain [21]. The mechanical properties of materials (Toughness and elasticity coefficients) are important properties in defining the parts goodness which are manufactured from these materials these properties are describe below [22, 23].:

1.5.1 *Fracture Toughness*

The resistance to extend a crack through a structural member may be characterized by the stress intensity of fracture K_C, called the fracture toughness. The Fracture Toughness and the manner in which the crack grows is heavily dependent upon the material thickness. [24, 25].

There are different methods for study the fracture toughness they are [26].

1. Crack extension force.
2. Crack opening displacement.
3. J - Integral.
4. R – Curve.

The crack opening displacement technique is a mathematical model and very important in predicting materials properties.

1.5.1.1 *Crack Opening Displacement*

The development of a plastic zone at the tip of the crack results in displacement of the faces without crack extension. This relative displacement of opposite crack edges is called the crack opening displacement (COD), fig (1-16)[14,16,26].

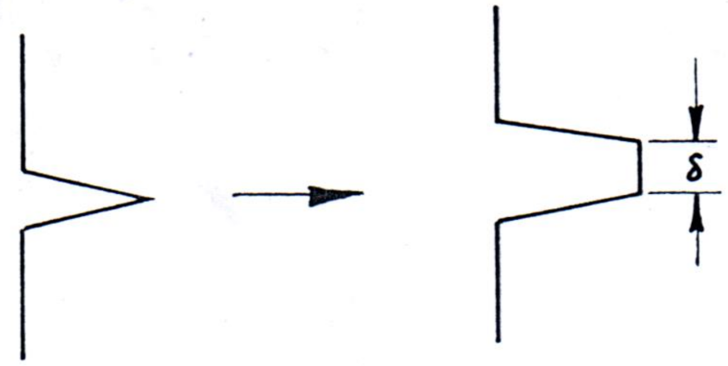


Fig (1-16) Crack opening Displacement

Consider a small crack in a brittle material, we have:

$$\sigma_c = k_{1c}\left(\sqrt{\pi a}\right)^{-1} \qquad \text{equ.(1-5)}$$

as $a \to 0, \sigma_c \to \infty.$

but this, as we very well know, does not occur. Instead, a plastic zone develops and may extend through the section such that[16,27]:

$$\sigma_{net} = \sigma \frac{W}{W-a} \geq \sigma_y \qquad \text{equ.(1-6)}$$

Where

W: width of sample

σ_y: the yield stress

In practice, $\sigma_y \leq 0.66\ \sigma_y$ for the K_{1c} validity.

In more ductile materials, the critical stress predicted by LEFM will be higher than σ_y. one can use the concept of COD in such cases. In the elastic case,.

$$COD = \Delta = \frac{u\,a}{E}\sqrt{\left(a^2 - x^2\right)} \qquad \text{equ.(1-7)}$$

At the center of the crack (x=0), the maximum opening is

$$\Delta_{\max} = \frac{4\sigma a}{E} \qquad \text{equ.(1-8)}$$

Applying the plastic zone correction, we have, from equ (1-7).

$$\Delta = \frac{4a}{E}\sqrt{\left(a + ry\right)^2 - x^2} \qquad \text{equ.(1-9)}$$

Where (a+ry) is the effective crack length.

The crack tip opening displacement (CTOD), δ is given for x = a and ry << a as

$$\delta = \frac{4\sigma}{E}\sqrt{2\,a\,ry} \qquad \text{equ.(1-10)}$$

A displacement of the origin to the crack tip gives a general expression for the crack opening:

$$\Delta = \frac{4\sigma}{E}\sqrt{2\,a_{eff}\;ry} \qquad \text{equ.(1-11)}$$

Substituting $ry = \sigma^2 a / 2\sigma_y^2$ in equ. (1-10) gives

$$\delta = \frac{4}{\pi}\frac{k_I{}^2}{E\,\sigma_y} \qquad \text{equ.(1-12)}$$

Fracture occurs when $k_I = k_{1c}$ which corresponds to $\delta = \delta_{Ic}$,

a material constant.

The use of COD criteria demands the measurement of δ_c we have

$$\begin{aligned}\Delta &= \frac{4\sigma}{E}\sqrt{(a+ry)^2 - x^2} \\ &= \frac{4\sigma}{E}\sqrt{a^2 + 2\,a\,ry + ry^2 - x^2}\end{aligned} \qquad \text{equ.(1-13)}$$

Ignoring the ry^2 term and using the relationship of equ. (1-10)

$$\Delta = \frac{4\sigma}{E}\left(a^2 - x^2 + \frac{E^2}{16\sigma^2}\delta^2\right)^{1/2} \qquad \text{equ.(1-14)}$$

Another way of obtaining δ is to use equations of

Dagdale – BSC model of the crack:

$$\delta = \frac{8\sigma_y\,a}{\pi E}\log\sec\frac{\pi\sigma}{2\sigma_y} \qquad \text{equ.(1-15)}$$

Expanding the log sec function in series, we get:

$$\delta = \frac{8\sigma_y\,a}{E\,\sigma_y}\left[\frac{1}{2}\left(\frac{\pi\sigma}{2\sigma_y}\right)^2 + \frac{1}{12}\left(\frac{\pi\sigma}{2\sigma_y}\right)^4 + \ldots\ldots\right] \qquad \text{equ.(1-16)}$$

For $\sigma << \sigma_y$ (neglecting fourth and higher order terms)

$$\delta = \frac{\pi \sigma^2}{E \sigma_y} = \frac{\sigma_I}{\sigma_y} \qquad \text{equ.(1-17)}$$

Comparing equ. (1-17) with equ. (1-12) we note that the difference is in the factor $4/\pi$, which comes from the plastic zone correction. In general,

$$\delta = \frac{G_I}{\lambda \sigma_y} = \frac{k_I^2 (1-\upsilon^2)}{E \lambda \sigma_y} (for\ plane\ \ strain) \qquad \text{equ.(1-18)}$$

λ = Constant

The factor $(1-\nu^2)$ should be ignored in the case of plane stress.

Fig (1-17) presents a comparison between COD and CTOD.

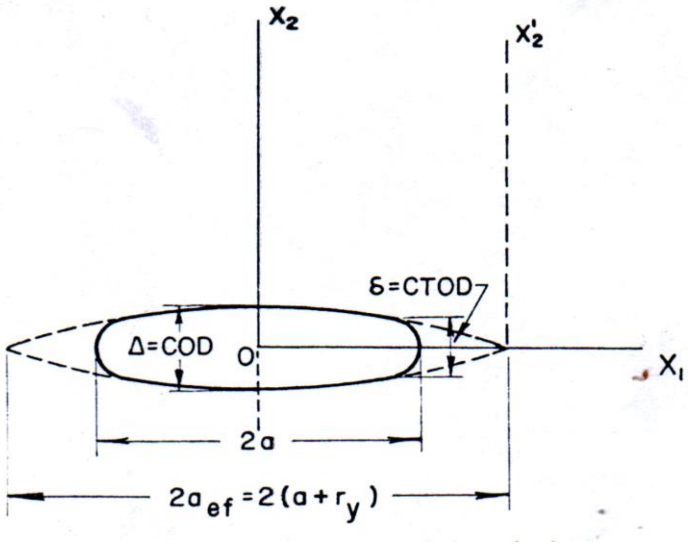


Fig (1-17) a comparison between COD and CTOD

There is another ways for practical tests of fracture toughness for measuring the toughness or impact strength

The Toughness is considered the ability of material for shock load and measurement this ability for applied shock force by impact test . In this test shock force is by a hammer, The energy for fracture is calculated [15]. The toughness of the material related to absorb energy for fracture [28]

$G_c = \upsilon / tw\psi$ ... equ (1-19)

Where:

υ - The absorbed energy (Joule)

ψ - Geometrical form function for notches sample with a depth and toughness of the material (G_c) related to fracture toughness (K_c) by the following equation [22]

$G_c = K_c^2/E$ equ (1-20)

Where K_c . Fracture toughness ($N/M^{3/2}$)

E – material elastic modulus

The impact strength considers the measurement for resistance material to fracture under applied force and it can be find from the following relation [29].

Impact strength = Energy required for crack/sample cross section area.... (1-21)

It is unit Joule / m^2 it is depended on various variable included type of the materials, strain rate, stress system, Geometry of Article , Fabrication and Environment conditions. [30].

The toughness of the material does not obey the law of mixtures and that happens in material depends very much on the strength of the bond between the components of fibrous composite while the situation is different with particulate composites and no comparable very large increases in toughness relative to that of the matrix material are attained . In fact, if high modulus particles are blended with for example, a tough semi crystalline Thermoplastic such as nylon to increase its stiffness, the toughness of the material decreases with increasing volume fraction of particles on the other hand, if the matrix is brittle some increase in toughness can be obtained [31, 32]. Figure (1-18) shows an electron micrograph of a thin section of high impact polystyrene and you can see the globules of rubber embedded in the polystyrene matrix. Rubber has a very much lower young's modulus than has a glassy thermoplastic, so the modulus of composite is lowered. However, the rubber volume fraction is only a bout 10% so that the effect on the modulus is not very significant. [31].

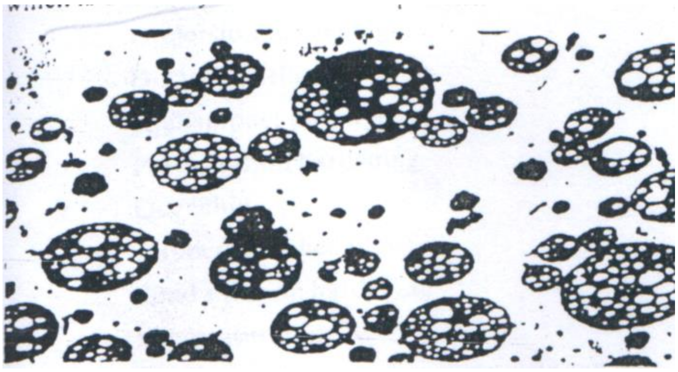


Fig (1-18) Electron micrograph of HIPS showing rubber globules in a polystyrene matrix [31].

The addition of rubber particles which carry practically none of the load creates an array of stress concentrations throughout the polystyrene, from which crazing can be nucleated. This leads to a much greater degree of crazing under fracture conditions, with a corresponding increase in the energy required the impact toughness can be raised by up to a factor of ten in this way. [31].

In the ductile, brittle behavior, since the fracture toughness is largely made up of the work term can write [31].

Toughness ≈ yield stress x plastic extension... (1-22).

To increase toughness we would like to increase both terms on the right – hand side of the equation , what determines wethere the toughness will be increased or decreased is the balance between the increasing yield stress and the decreasing a mount of plastic deformation [33].

1.5.2 *YOUNG’S MODULUS*

Young's modulus defines as the ratio between the applied stress and the strain result from it in the elastic region in the stress elongation as shown in fig (1-19).

The slope resembles the ratio between stress to the strain is called Young's modulus of elasticity

$$\text{Modulus of elasticity} = \frac{\text{Applied Force / Area}}{\text{Change in Length / Original Length}} = \frac{\text{Stress}}{\text{Strain}}$$

$$E = \frac{P/A}{\Delta L/L^{\circ}} \qquad \text{equ (1-23)}$$

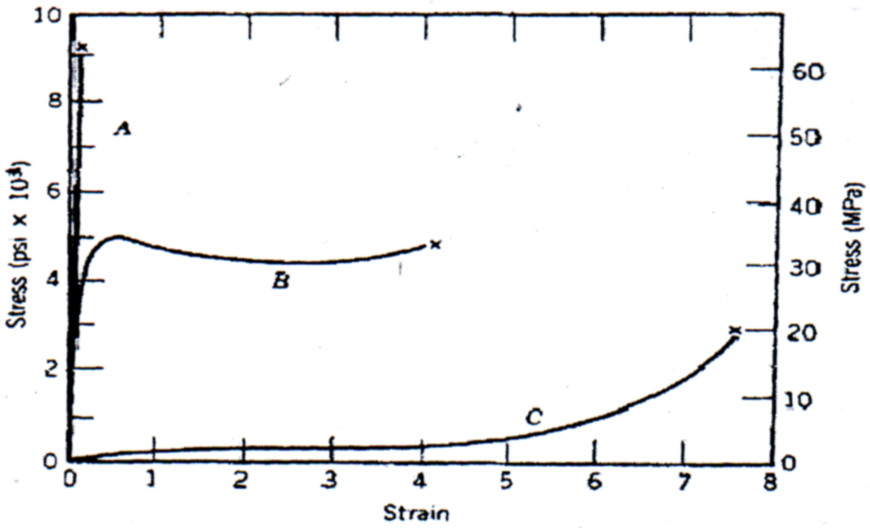


Fig (1-19) Strain behavior (A) thermoplastics display both ductile and brittle behavior (B) thermosets tend to be brittle (C) elastmers tend to have low E and to display non-behavior [30].

For homogenous materials like steel the young's modulus for compression and tensile strength unequal, while for non – homogenous materials like bone the young’s modulus for compression is larger than the state of tension because the cracks and defects tend to close up where the Brittle Materials are much strength in compression than tension [23].

1.5.3 *Hardness*

In engineering application, hardness is commonly defined as the resistance to indentation. Indentation is the pressing of a hard object with a definite shape and with a definite load against a material. The indentation plastically deforms the material and leaves a depression. A measure of hardness of the material is obtained from either the size or the depth of the depression. There are different tests can be used as a measure of hardness, scleroscope hardness tester, scratch test Brinell and the Vickers tests[16,17].

The Rockwell hardness test that measures the depth of penetration of the indenter. There are a number of scales used for Rockwell. Hardness tests that involves the combination of the appropriate indcater and the required load [6].

The hardness test is the commonly use with respect to the mechanical properties and it is preferred due to [34].

1- It is easy test and cheap of the used Equipment relatively and do not need preparation especial sample.
2- It is nondestructive where the sample don’t highly form (The deformation is only fine Hole)
3- It is useful to calculate other properties like tensile strength and fatigue strength [6.

1.6 *Nondestructive Testing*

After the part is fabricated, the part normally subjected to nondestructive testing. These tests used to characterize both uncured resins and cured composites [1, 6. In this work, we used two kinds of non-destructive tests; the first is chemical test which is Fourier Transform Infrared spectroscopy (FTIR) and the second ultrasonic test to find the young's modulus for specimens of the work.

1.6.1 *The Fourier transforms Infrared Testing*

Infrared (IR) spectroscopy is based on molecular vibrations in which a continuous beam of electromagnetic radiation is passed through or reflected off the surface of the sample, which may be a solid, liquid or a gas. Individual molecular bonds and bond groups vibrate at characteristic frequencies and selectively absorb IR radiation at matching frequencies [1].

The amount of radiation absorbed or passed through unchanged depends on the chemical composition of the sample and the resultant curve is known as an IR spectrum, as shown in fig (1-20)

IR spectroscopy can also be used to identify the specific ingredients comparing the sample with a computerized spectrum search.

IR spectroscopy is sensitive to changes in the dipole moments of vibration groups of molecules, which yield useful information a bout the identify of the resin components. It also provides "fingerprint" of the resin composition, Fourier transform IR spectroscopy (FTIR) is a computer – assisted method in which Fourier transformation of the IR spectra is used to enhance the absorbtion bonds tonoise ratio and provide improved spectra for interpretation. computerize libraries of spectra for common materials exist for direct comparison an identification of the resin ingredients. [1,13].

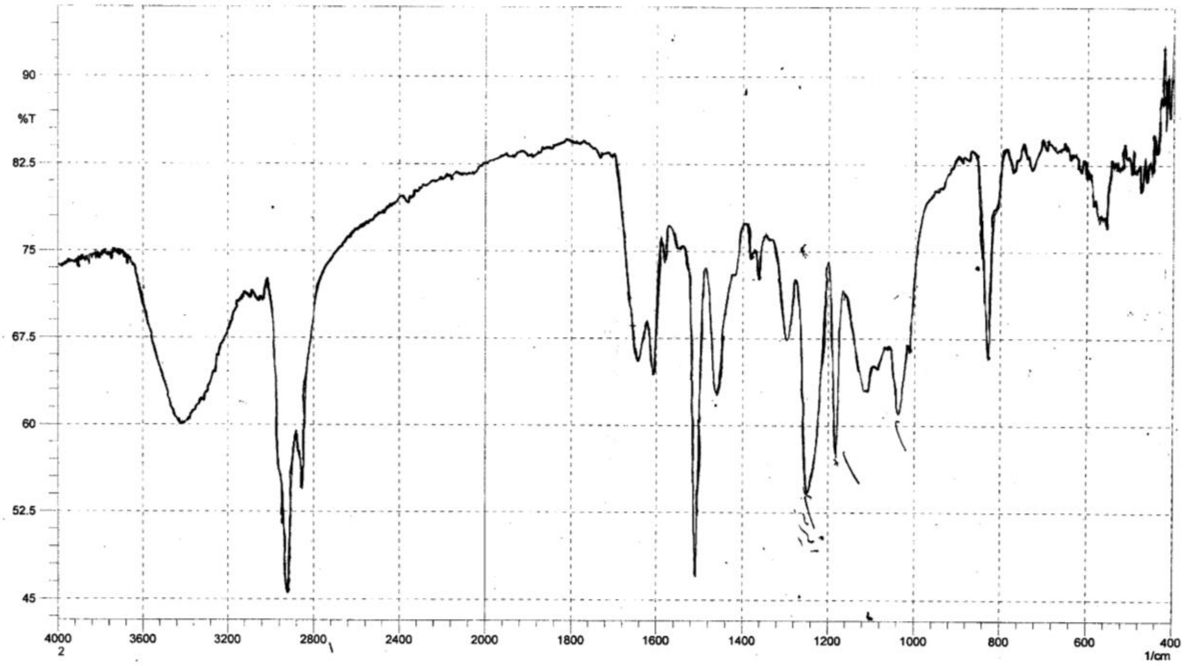


Fig (1-20) Finger print of epoxy resin

1.6.2 *Ultrasonic test*

Ultrasonic inspection methods are probably the most widely used form of NDT.

Ultrasonic waves are produced when an electrical signal generator sends a burst of electrical energy to a piezoelectric crystal in the transducer causing the crystal to vibrate and convert the electrical pulses. Into mechanical vibration (sound waves) the piezoelectric crystal will also convert the returning sound waves back in to electrical energy when the sound is received the pulse . Flaws are detectable since they alter the a mount of sound returned to the receiver. [1]

Ultrasonic waves in composites are highly attenuated to the heterogeneous nature of the materials and response is strongly dependent on frequency; a typical range being 1-10 MHZ.

In formation regarding the defect can be obtained from amplitude and transit time of reflections.

Measurement of ultrasonic velocity can be useful for the measurement of dynamic modulus and density for an isotropic material, the relationship between velocity and modulus is given by [12].

$Ed = \rho V^2$ equ (1-24)

Where Ed = dynamic elastic modulus (MN/m^2)

Where ρ= density (Kg/m^3)

Where V= pulse velocity (Km/s)

Where V= L/t .... (1-25)

t= The travel time of the ultrasonic wave .

L=Length of samble

Fig (1-21) shows a comparison of dynamic modulus values measured by ultrasonic and resonant techniques . Results are in reasonable agreement with expectations . The greatest deviation being ±45 to the material axes. [11].

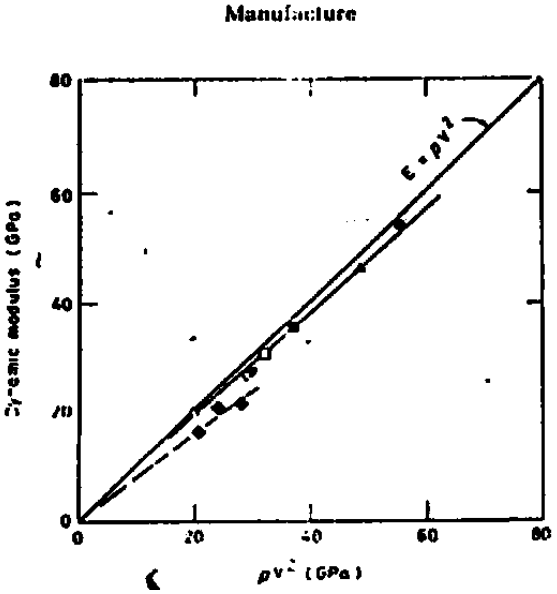


Fig (1-21) Comparison of Ultrasonic and resonance modulus measurement methods [11].

This test determines the velocity of logitudinal (compressional) waves, this determination consists of measurement of the time taken by apulse – hence the name of the method – to travel ameasured distance. The apparatus includes transdues which are placed in contact with the sample, apules geuerator with afrequency between 10 and 150 Hz, an amplifier, a time measuring circuit, and a digital display of the time taken by the pulse of longitudinal waves to travel between the transducers [35].

1.7 *Literature Survey*

There are many studies about the using of compounding process to obtain blending polymers and polymer matrix composite to improve and enhance mechanical properties for usage in a variety of applications.

The reinforced plastic is used to make the plave’s pruplen at (1950). [21]

Myaegchenen kov (1963), [36], study the polymerization of polymthylemethacrylic (PMMA) with unsaturated polyester (UPE) and investigated surface hardness and glass transition temperature of the new blend .

The approach is the increasing of surface hardness and glass transition compared to their values of (UPE).

Bascom (1980), [22], studied the fracture energy of inter- laminar for composites energy of fiber glass and graphite incorporated in epoxy matrix and obtain increasing of fracture energy by using thermoplastic material instead of epoxy or adding elastomeric material to the epoxy, which has high modulus makes fracture energy of inter- laminar low;

therefore, these elastomeric materials are added to do diffracted phase in resin and the problem of fracture energy is solved .

J.K. Gillham and L.T.Manzione (1981), [23], study the surface morphology and mechanical properties of rubber- modified epoxies and found that result material has high strain at fracture also high toughness.

Raj, et al. (1982), [37], presented the impact properties of the various glass fiber – rein forced composite and their fracture mode under dynamic load. The results of dyanmi cload were compared with those of corresponding to static. They concluded that the impact strength of the most of composite material (as glass fiber rein forced composite) depends on its ability to absorb the energy, resist the dynamic load, hardened system, and curing conditions (such as the time) ; impact strength goes to the maximum value at a certain curing time and decreases after and before this time. In the other hand, they concluded that the composite materials sustain higher impact and show excellent impact strength.

M.M. Coleman and E.S. Moskala (1983), [38], study the polymer blends of phenoxy with poly carbolacton (pcl) and the phenoxy with polyethylene oxide (PEO) by using radiation, the opproach is presence of strong intermolecular hydrogen bonds between the group of carbonyl in (pcl) and group of hydroxyl in phenoxy.

S.C.KUNZ (1984), [39], study the behavior of rubber modified epoxy at low temperatures. Results showed that values of fracture is greater than its value of epoxy alone.

Maxwell and kinlock (1985), [40], study the behavior of particulate composite of glass and rubber particles, they found increasing the epoxy toughness by using glass and rubber particles (hybrid), where the addition of 10% volume fraction of the glass particles make the composite material processes high modulus with addition to high toughness due to the effect of rubber particles.

Amarc. Gary and yin – wing mai (1988), [41], had been study the failure mechanism of the epoxy resin with and without the carboxyl group(CTBN) rubber additives, this addition improved the epoxy toughness of (30) time at the master epoxy. In spite of this good result but the use of toughened epoxy don't give desired toughness with respect to first state.

S.N. Tong and peter T.K. We (1988), [42], in their work used different methods to improve the toughness of unsaturated polyester (UPS) by compounding it with rubbers and thermoplastic polymers; the result is high toughness but low in tensile strength and hardness.

The rubbers that used were from butadiene and acrylonitrile copolymers and had hydroxide group (HTBN), carboxyle (CTBN), phenol (VTBN) and amine (ATBN), while the thermoplastic polymers were polyethylene glycole and polycarbolact (pcl).

J. Peter man and T. Asona (1990), [43], prepared a polymer blend of polyoctytiamer (TOR) with polypropylene (pp), from the study of mechanical properties, they approached that young’s modulus and fracture stress increased and this increasing was continuous to limit 30% (TOR) and after this ratio, the values would decrease.

N. Amdouni (1990), [44], studied epoxy matrix was reinforced with 20 % volume fraction of the glass particles and found that there were different methods to improve fracture toughness either by using rubber phase to epoxy or using adhesive material between fillers and matrix

P. Ghosoh and N. Bose (1995), [45], study the addition of small amount of rubberic polymer such as the styrene butadiene rubber (0.1-

0.2)% and the liquid of poly butadiene at ratio (0.5-0.75)% to unsaturated polyester, the impact strength was increased for composite material.

Kun – chunteng (1996), [46], studied the blends of epoxy with phenoxy , he also studied their surface morphology and mechanical properties and found that the blend was either homogeneous or in homogeneous by controlling of the amount of accelerator in system, and noticed that homogeneous blend that the highest ratio of phenoxy added to (EP) gave the highest fracture toughness and the mixture showed decreasing in glass transition temperature (tg), young's modulus and yield stress, also in the state of in homogeneous blend, fracture toughness increases with increasing phenoxy content.

Sufen mao and ying. Li (1996), [47], study the blend of ploy-urethane (PU) and epoxy (EP), the results agreed that good compatibility between the two polymers when the ratio of PU/Ep was 30 /70, in another research they approached that these structures have high tensile strength, high strain and high fracture energy at ratio 30/70, the reason was that (PU) effected as plasticizer on epoxy where the linear chains of (PU) linked with the cross – linked network of (EP) by physical cross – linking points and then chains slide and took their position in tensile field without destroying of chains ; therefore, the chains gave high elongation and high tensile strength.

G. Levite (1997), [48] , study the interface strength of composite based on epoxy blends with acrylonitrile butadiene, the glass and carbon black fiber were the reinforcements. His approach that presence of rubber with epoxy increases its toughness and decreases the adhesion between the fiber and the matrix at rubber content (1.5 -2.5) % weigh fraction and modified the viscoelastic behavior of composite material.

K. AL-Rawi (1998), [49], study the compatibility of blend system and its effect on some physical and mechanical properties, the thermoplastic and thermoset polymers were used and found that its possible to obtain binary polymer blends of poly – methyle-metha- . acrylic (PMMA), poly styrene (PS) , poly urethane (PU) , unsaturated polyester (UPE) and epoxy (EP). with variation of ratio that gives the complete compatibility, at which ductility and thermal stability is the best and the increasing and decreasing of fracture toughness depends on the type and concentration of components of blends , in creasing of hardness because aging process.

G.R.Furtadoa (2000), [50], study the mechanical properties of composites of mica, silica and styrene butadiene. The low content of mica caused increasing of young's modulus and no effect on tensile strength and elongation at fracture. The addition of silane as a coupling agent strengthens the bond between the rubber and silica and have opposite effect on fatigue life.

H.I.Jaffer (2000), [51], investigated the interlminer toughness of rein- forced polymer blends, he used chopped fibers of glass for (10% ps/90% EP), (20% pu/80% EP), (80% UPE/20% PU) and (20%PS/80% EP), the behavior of (EP) and (UPE) was brittle in tensile test and hard behavior when added (20%) weight fraction of polyurethane (PU) coming to increasing elasticity of the two polymers. The addition (10%) and (20%) weight of (PS) to (EP) will effect on (EP) and make its behavior viscoelastic.

The reinforcement of epoxy blend at 20% weight fraction of (PU) and 10% and 20% of (PS) increases impact strength of composite while decreases at addition 20% (PU) to (EP), results of bending test showed that composites based on polymer blends had higher interlaminar toughness than incase of the base was one polymer.

The Bobby Russell (2000), [18], used empirical and theoretical models in the prediction of properties in rubber toughened epoxies.

He used the crack opening displacement techniques to determine the crack radius of crack tip. The finite element method was used to analysis the nature and magnitude of shear banding.

H.A.AL-Falahi (2000), [52] , prepared composites of navolac base as insulators in jet of rocket engine and investigated them. The results showed increasing compression strength, shear strength and tensile strength for composite of carbon black fibers (H36) compared to those for composites of chopped carbon black and silica (H46,H41), while bending and impact strength of composite (H46) were higher if the composites (H36,H41) and this evidence that the type of fiber, type of filler, type of resin and method of preparation of samples have effect or mechanical properties.

H.Z.Al. Ithary (2000), [53], studied the behavior of unidirectional composite material by using the micromechanics approach. The FE model (SAOVDL) is built by using quick basic language. The model verified by comparing with the studying case from anther anthers on designed computer program . the result of this program has a good agreement.

N.A. Saad (2005), [54], studies the effect of material strength and processing parameter on stress – stain distribution during the forming process. He uses the FEM in the analysis of thermoplastic sheet (LDPE / Nylon 66) forming by using the rubber pad forming technique.

The modeling and simulation are implemented by using the FEM ANSYS 5.4 code in his studying proved that the model which was built by using the FEM is very active to study effect of the processing parameters on forming process.

1.8 Aim of this work

Epoxy resins are important in different industrial application especially in the category of aerospace applications such as aircraft, helicopters, missiles, reentry, and other aerospace vehicles low density coupled with other desirable features but the epoxy resins undergo of some problems such as brittleness and that leads to unprofitable use for such applications and certainly dynamic forces; Therefore, this study objects to:

1. Improve epoxy toughness by using elastomer polymers such (SBR) by powder and liquid techniques.
2. Reinforcement of toughened- epoxies by chopped fibers of volume fractions of polyamides which is treated with coupling agent with rubber material to improve the decreasing of specific strength due to toughening.
3. Constitution mathematical models to prediction the effect of additives on mechanical properties such as fracture toughness before practical testing by using finite element methods FEM.

Chapter Two

Modeling Process and Numerical Simulation

2.1 *Introduction*

The detail understanding of toughening mechanism is required and it is important to control the parameters, which affects this mechanism. The theoretical analysis is very important to prediction the role of every one of these parameters on the toughening mechanism. Although there are a most wide theoretical study about this field but it still not sufficient and it is required; in the Present work. A FE analysis is used to study the effect of some parameters such as rubber additive volume fraction, rubber add techniques (Liquid, Powder) on the mechanical properties at the product composite material. This micro mechanisms analysis approach is used within the modeling process. Two dimensions models were carried out by using the ANSYS 5.4 code.

2.2 Assumption

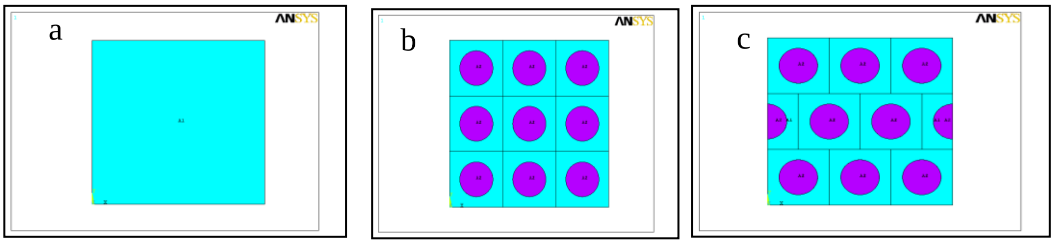
To simply the modeling process there are different assumptions which are used:

1. Assume perfect bond between the matrix and toughening particles.
2. The uniform structures for matrix and toughening particle (no voids).
3. the arrangement of toughening particle in matrix is (random).
4. The toughening particle shape is spherical and of the same size.

2.3 Models Constitute

Two models are built are:

1. Compression test model: this model is used to describes the structure of the sample after prepared it with different rubber volume fraction .FEM depends on the micro mechanics approach. The unit cell consists of epoxy and rubber particles that are built. The dimensions of unit cell is (3.2×3.2) µm where rubber particles arrangement is assumed as Zigzag as shown in fig (2-1)..and the diameter of rubber particles is (different with volume fraction of rubber) µm as shown in fig (2-2)..



a-Pure epoxy b-uniform c-zigzag

Fig (2-1) types of unit cell in the compression model

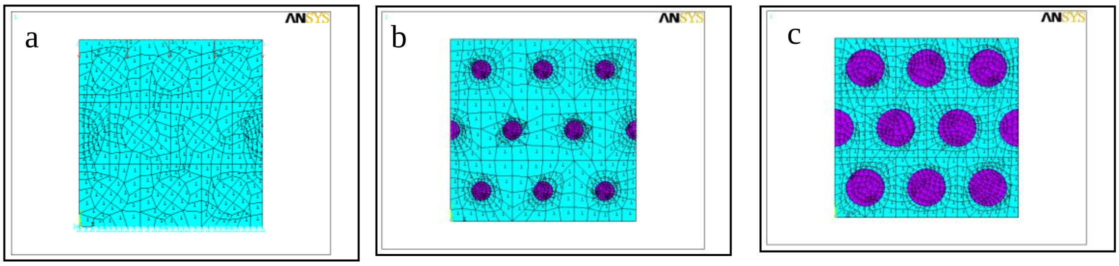


Fig (2-2) finite element model with different rubber volume fraction of rubber

a-Pure epoxy b-(15% rubber+epoxy) c-(3o rubber+epoxy)

The volume fraction is of 0 to 30 percent. Two techniques are used in this model by changing the rubber property model. The material property and the elements which are used in this model are shown in table (2-1) also the behavior of these material under this loading condition is described by using these type of element which are a function of mathematical model of the material behavior as follows :

A-Modeling of hyper-elastic material (rubber material)according to (Moony Rivlin) functions ………(1) which are used in ANSYS 5.4 code . This function is available in the element (Hyper 56)used in this model : this λ parameter is shown in fig (2-3)

$$U = C_1(I_1 - 3) + C_2(I_2 - 3) \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$

$$I_2 = \lambda_1^2\lambda_2^2 + \lambda_1^2\lambda_3^2 + \lambda_3^2\lambda_2^2$$

$$\lambda_1^2 = 1 + 2e_{xx}$$

$$\lambda_2^2 = 1 + 2e_{yy}$$

$$\lambda_3^2 = 1 + 2e_{zz}$$

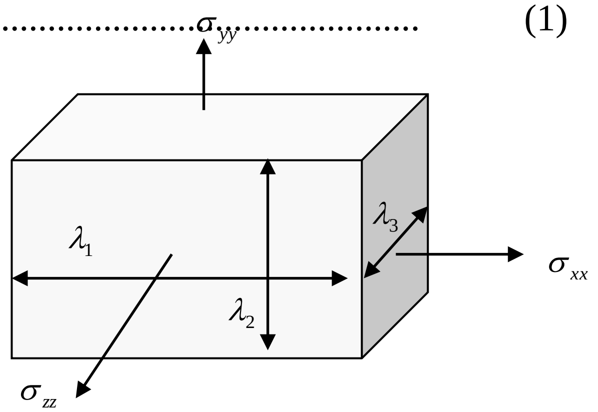


Fig (2-3) Extension ratio (λ) in x, y and z direction

A- Modeling of solid structure material (epoxy) by using solid 42 element . This element contains this function ……. (2)which used in ANSYS . 5.4 to describe the elastic behavior of material (epoxy) because of the deformation in this part it must not exceed the elastic range .

$$\sigma = E\varepsilon \quad \ldots\ldots\ldots\ldots \quad (2)$$

Table (2-1)

Materials	E	Element
Epoxy	$30*10^3$(MPa)	Solid 42
Rubber Solution	0.68 (MPa)	Hyper 56
Vulcanized Rubber Powder	2.82 (MPa)	Hyper 56

s

2. The toughening model: the finite element model of crack opening displacement approach is built for the simulating impact specimens with notch size (2*2) and radius is (1)mm. as shown in fig (2-4).

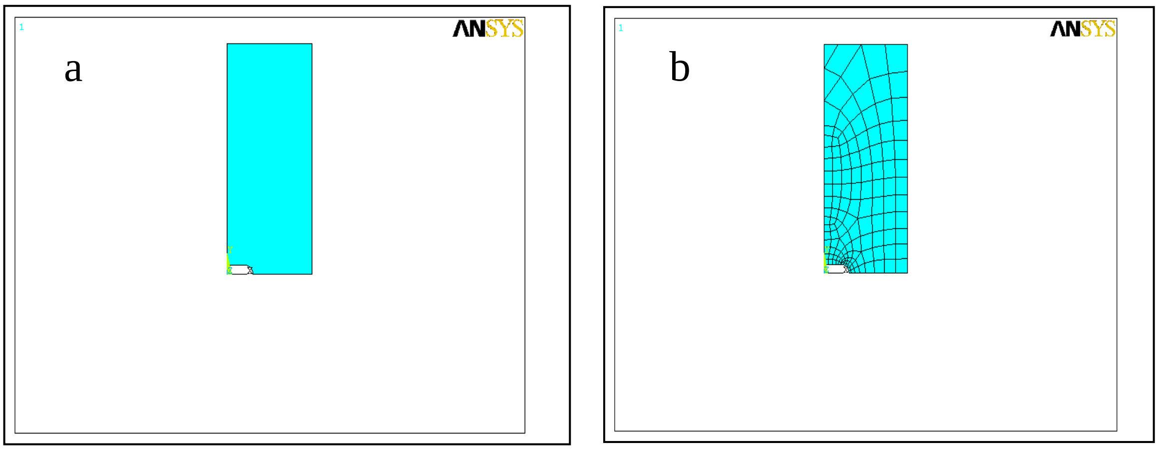


Fig (2-4) a. sample geometry

b . Finite Element Model of the crack opening displacement

2.4 Mesh Generation

The models are meshed by using automatic mesh generation process and the element configurations and size are as shown in the fig (2-3),(2-4b) to obtain the best result of the modeling process and the models become more active to describe the real case of the analysis .

2.5 Paramedic Study:

1- Volume fraction of toughening phase (0,15, 30) %
2- Rubber Additives Technique.

2.6 Result Output:

The result is recorded for the stress and the strain for different volume fraction and techniques as contour and curves at any point and then the modulus of elasticity can be calculated . As example a contour result of stress and strain are shown in fig (2-5 , 2-6) . the total results are listed and discuss in chapter four.

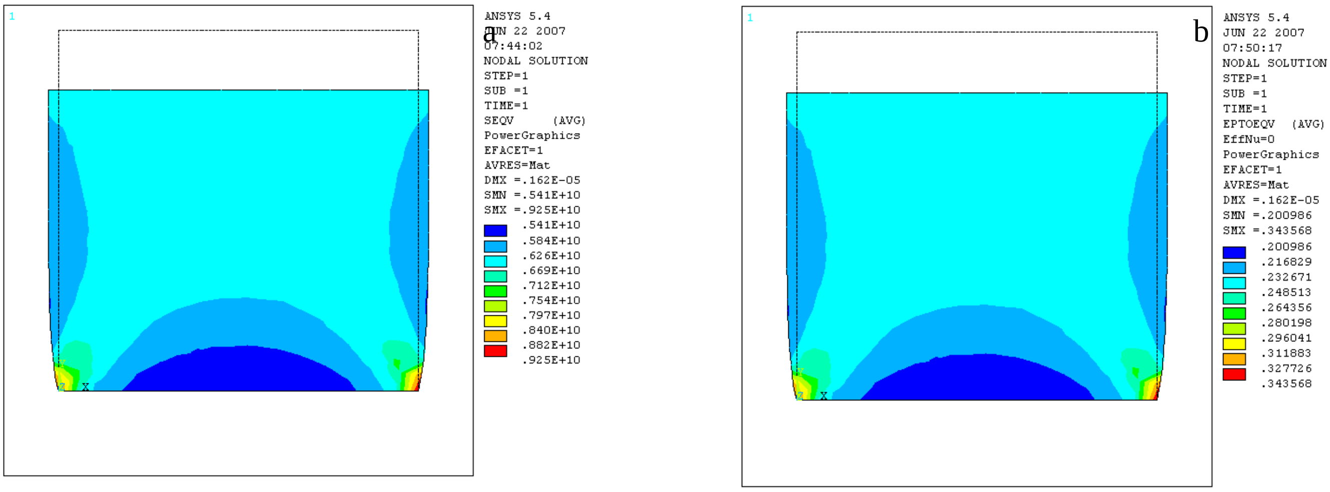


Fig (2-5) numerical results
a- stress Von Mises for 0 % volume fraction of rubber
b- strain Von Mises for 0%volume fraction of rubber

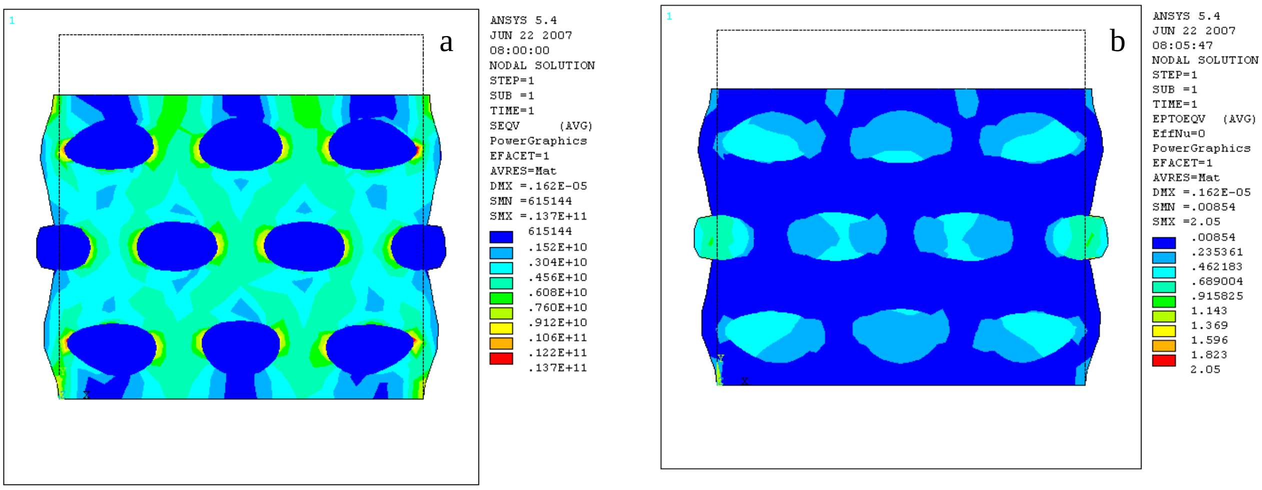


fig (2-6) Numerical results
a- stress Von Mises for 30 % volume fraction of rubber
b- strain Von Misis for 30 % volume fraction of rubber

Chapter Three

Practical part

3.1 Introduction

To verify the accuracy and the validity of the numerical models and the simulation process to add rubber to epoxy, the experimental work is conducted includes three stages:

1- Preparation of the raw materials (fiber, epoxy, additives) to make blends, composite materials and evaluate their properties.
2- Description the procedure which are used to prepare samples of blends and composite materials for all the used tests, with their standard dimensions.
3- Description the tools and equipment in this work, their photographs, and the supply company.

3.2 Used Materials

1. Matrix

The matrix materials which are used is the epoxy, type of (ARCAABON DR 900H), its chemical composition (Bisphenol–A–Epoxide harze). The epoxy is viscous liquid, it converts to solid state when addition the hardener type of (ARCADUR R 900H) with chemical composition (N, N–Di Methyl Di propylene Triamir) at ratio nearly 1:1 at room temperature. Specifications of epoxy are listed in table (3-1).

Table (3-1) Specifications of epoxy [11] .

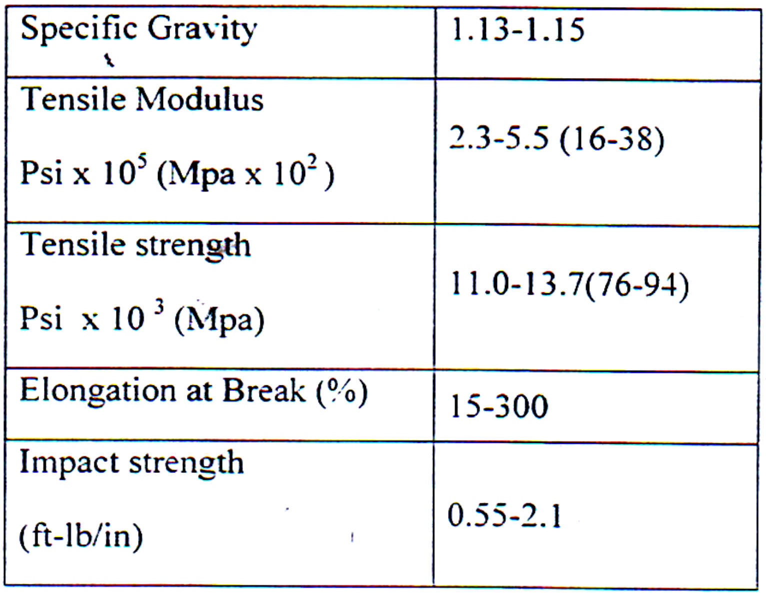
Property	Epoxy
Specific gravity	1.2 – 1.3
Rockwell hardness	M100 – M110
Impact strength (Izod) (J/m)	8 – 80
Thermal Conductivity (W/m/°C)	0.17 – 0.21
Thermal expaensivity	5 – 8
Specific heat(kJ/kg/°C)	1.25 – 1.80
Volume receptivity (Ωcm)	10^{17}
Dielectric constant (at 60 Hz)	2.5 – 4.5
Tensile strength (MPa)	55 – 130
Flexural strength (MPa)	125
Tensile modulus (GPa	28 - 42

2. **Fibers**

In this work, poly amide (Nylon 6/6) fiber was used to reinforce the matrix. This nylon treated by chemical materials to increase its adhesion to the rubber, thus it is called structured dipped.

Its specifications are listed in table (3-1)

Table (3-2) Nylon specification [55].



Specific Gravity	1.13-1.15
Tensile Modulus Psi x 10^5 (Mpa x 10^2)	2.3-5.5 (16-38)
Tensile strength Psi x 10^3 (Mpa)	11.0-13.7(76-94)
Elongation at Break (%)	15-300
Impact strength (ft-lb/in)	0.55-2.1

3. **Additives**

The styrene – butadiene rubber is obtained from Babylon Tyre Company. It is added to the epoxy resin in two techniques:

a-Rubber Solution.

b-Vulcanized rubber powders.

The specification of these additives is shown in the table (3-3)

Table (3-3) - Specification of Rubber additives[55]

Characteristics	Unit	Requirements
Specific gravity (Typical)	gm/cm^3	0.92
Volatile matter	%	0.7 maximum
Ash content	%	1.00 maximum
ETA extract	%	4.75- 7.75+stabilizer
Bound styrene	%	23.5 ± 1.0 maximum
Organic acid	%	4.7-7.2
Stabilizer	%	Advised by supplier
Viscosity ML(1+4) 100°C	%	52±3

3.3Preparation of Polymer Blends Techniques

The epoxy blends were prepared according to the following procedure:

1. **Mould Made**

To prepare the impact materials specimens. The impact samples die was made of carbon steel with dimensions(200*100*15)mm to produce these samples by the casting process as shown in fig (3-1). Sample s dimensions are (55×10×5) mm.

2. **Die Finishing**

This process is used to ensure that the resin doesn’t adhesive in the mould after the curing process, polishing the mould by emery papers at different degrees (180, 400, 800, 1000), and then the mould is painted by varnish as a transparent insulator.

3. **Preparing of SBR Solution**

It’s prepared by addition the heptan liquid at ratio 3:4, and then the ratio of rubber that dissolves in heptan liquid determines by weight amount of rubber solution (heptan + rubber) such as 5.016g, the mixture put in oven at degree 100°C for (1) hr or (two sunny days), then calculate the volatile the heptan after evaporation from piker weight.

The weight unfilled piker = 19.132g

The weight of rubber solution before evaporation = 5.016g

The actual rubber = 4.722

$$\text{The ratio of heptan} = \frac{\text{Weight of solution before vaporation} - \text{weight of solution after vaporation}}{100} \quad ...equ.(3-1)$$

This ratio added to weight ratio of rubber solution .The SBR solution is added at weight fraction (2.5%, 5%, 10 %).

4. Preparation of epoxy resin.

   It's prepared by addition the hardener at ratio 1:1 and mixing them manually.

5. The addition of the solution rubber to epoxy resin and mixing them.
6. Blends are casting in the mould.
7. Remained the blends for (24) hr, where the fast post curing causes failure of all samples , therefore the curing process

must be conducted by following the cycle of curing that mentioned in theoretical part. the mould process is conducted at (100°C) for (1) hr to reduce the internal stress which are being through shrinkage and also to obtain a good cross – linking.

8. Release specimens before coldness of mould to avoid adhesive the samples to the mould.
9. Preparation of specimens for tests by trimming the specimens according to the standard dimensions are used in the tests, then grind them by using emery papers at degrees (180, 400, 800, 1000).

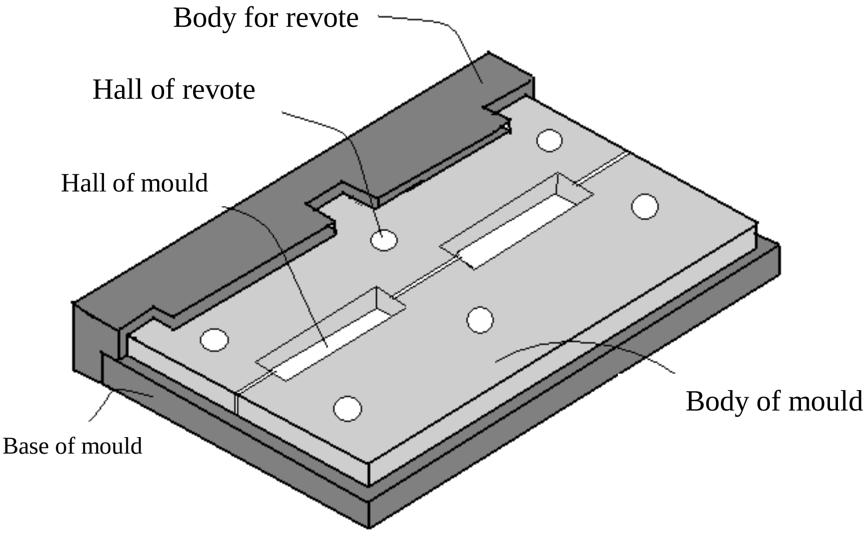


Fig (3-1) Configuration of Mould

3.4 *Preparation of Polymer Composites Technique*

Hand lay – up molding is used for preparation of polymer composite materials by following procedure:

1. The Preparation as in previous section (1, 2, 4, 5, 6, 7)
2. The Preparation the vulcanized SBR powder. The vulcanized powder of SBR is prepared by using different type of files in different grain size ((0.5) µm-(5) µm).

3. The Preparation the tough composite material(blends), of particulate material of vulcanized SBR powder with base of epoxy. The particles of SBR is added at weight fraction (2.5%, 5%, 10%) .The particles is weighted by using mass measurement instrument. The epoxy also prepared by adding its hardener and mixing them. The powder is added the prepared epoxy and also mixing them to obtain full miscibility. The mixture is casting in the previous prepared mould to obtain the desired thickness.

4. The Preparation the strength composite material. It's based of epoxy and nylon. Nylon 6/6 is cutting at length the (3- 10) mm to obtain chopped fibers, and then the weight of them is calculated and added at 50% weight fraction.

5. The Preparation of the hybrid Composite: It is hybrid composite containing particles and fibers, based on epoxy that prepared by addition the hardener at ratio 1:1 and mixing them well by hand. Powder of vulcanized SBR at weight fractions (2.5%, 5%, 10%) is mixing with the base epoxy, then chopped fiber of nylon 6/6 at the same length and the same weight fraction for strength composite material are added to them and casting in the mould.

6. Left mould for (24) hr in a room temperature then, it is put in oven for (1) hr at (100) °C.

7. The prepared samples of blends and composites are:

a-pure epoxy.

b-prepared samples of epoxy + rubber liquid at ratios (2.5%, 5%,10%) consequently.

c-prepared samples of epoxy + rubber vulcanized powder at ratios (2.5%, 5%,10%).

d-prepared samples of epoxy + CHF + rubber liquid at ratios (2.5%, 5%,10%) consequently.

e-prepared samples of epoxy + CHF + rubber vulcanized powder at ratios (2.5%, 5%,10%).

Fig (3-2)show ex of them

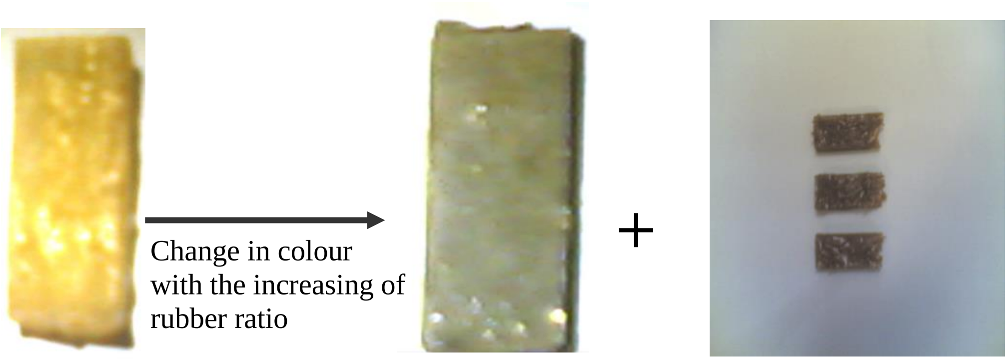


Fig (3-2)showes example of the prepared samples

3.5 Used Equipment

To prepare the samples for destructive and non – destructive tests to know the chemical composition and mechanical properties after post curing such as impact strength, young's modulus and hardness. The following equipment is used:

3.5.1 Equipment for mass measurement

It is Germany, type of (sartorius laboratory) model (L220 S-d), number (39090002) with accuracy of 0.001g.

3.5.2 Equipment for microstructure measurement

The microscopic type ALTY is used to photograph rubber vulcanized powder of SP.

3.5.3 Drying Oven

Drying oven type (300), model (15D) with temp. (100 – 550)°F, (Phoenix product company, inc).

3.5.4 Equipment for Impact measurement

Impact test is conducted by using Charpy method, its type (MK–0.5.1), in State Company for Mechanical Industries.

It's used for reinforced plastic, glass and wood, it consists of hammer and energy pointer . Energy is represented as following,

(Weight of hammer × height of hammer)

The impact strength of samples are calculated of the ratio between the required energy of fracture on cross – section area of the specimen.

Fig (3-3) Show the Configuration of Equipment of Impact.

3.5.5 Equipment for Hardness Measurement

The Rockwell hardness test is one of the measurements of the penetration of rigid ball into specimen under specified conditions.

Fig (3-4) shows a configuration of equipment for hardness, model (HLN-11A), its Germany and micro pointer.

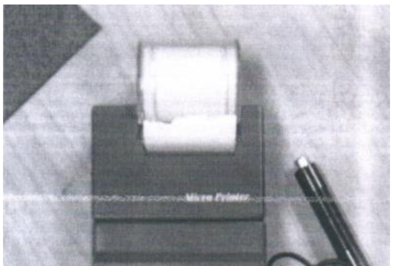


Fig (3-4) Equipment of Hardness

3.5.6 Equipment for FTIR Spectroscopy Measurement:

FTIR Spectroscopy Equipment used to conduct the chemical analysis of samples structure to know the effected of groups and compounds inside them. Fig (3-5) shows the configuration of FTIR Spectroscopy Equipment .FTIR spectrophotometer shimad 24-8400s.

Fig (3-5) Equipment of FTIR Spectroscopy

3.5.7 Equipment for Young's Modulus of Elasticity Measurement:

Non – destructive ultrasonic test is used to measure dynamic young's modulus of elasticity. It determines from the ratio between the velocity and the longitudinal (compress ional) waves (sample length)from equ. (1-24,1-25).this equipment shown in fig (3-6).

Fig (3-6) shows the configuration of Equipment of Young's Modulus of elasticity.

Chapter Four

Results and Discussion

4.1 Introduction

This chapter shows briefly all results obtained from the numerical and analysis to study the effect of the different parameters are (Volume fraction, rubber addition technique) on the epoxy toughening and other properties.

This chapter is includes the experimental results and discussion of the effect of the addition rubber liquid of SBR on the mechanical and chemical properties of epoxy, effect of the addition of rubber vulcanized powder of SBR on mechanical and chemical properties of epoxy, effect of the addition chopped fiber of polyamide on mechanical properties of polymer blends and toughened materials.

4.2 Effect of Rubber Liquid percentage on the mechanical properties of epoxy

It's known that the mechanical behavior of binary blends of polymers is very complicated because its related of some parameters such degree of Miscibility and Crystallization, Interfacial adhesion, conditions of preparations and testing [49].

From the observation of fig (4-1,a) we observe that the impact strength value increases with increasing the rubber liquid percentage with uniform slope and that is due to increase the toughness of the product blend (epoxy + rubber liquid). [18].

The toughness improvement results from the interaction between the epoxy network and elastomer network with increasing rubber liquid percentage leads to increasing the mobility of sections of polymer series in epoxy, this enable it to absorb high energy; Therefore; the epoxy toughness is increased [56].

The results of this research are agreed with the results of Ying Li and Sufen Mao when they studied of semi – IPNS for blend EP / PU and the approach to increase value of fracture energy with increasing the percentage of PU [47].

In the fig (4-1,b) and (4-1,c) where the hardness value of the different prepared types of the blends are agreed with the previous result of Impact Strength. The increasing of toughness is recognized by the toughening test and verity by another mechanical testing such as hardness and dynamic modulus of elasticity as shown in fig (4-1,b) and (4-1,c) where the hardness value of the different prepared types of the blend (epoxy + rubber liquid) agreed with the previous result of impact.

The hardness value is decreased with the increasing of the percentage of the rubber liquid except the anomalies value at the (2.5% rubber liquid) and that because the case of the reverse of anti-plasticization which is resulted from the increasing of the density of the blend which is resulted from the regular compatibility of the polymer series which is obtained from the little addition from the plasticizer [57]. increasing of density because of packing or increasing the interaction and reduction vacancy and pre- cavitations which expected in the individuals polymer or polymer without addition.

These values (hardness and impact strength) agree with the dynamic of elasticity behavior for the prepared samples as shown in fig (4-1, c).

These changes which are resulted from the addition of rubber liquid can be explained in details with the chemical analysis of the prepared blends.

The results of the dynamic modulus of elasticity behavior decrease with increasing of the percentage rubber liquid from 0 to 2.5 and then it begins with increasing of the percentage of low range. The change in this behavior belongs to the increasing of the plasticity value in the low additive of rubber liquid but the increasing after that because of strengthening by create new chemical bond as shown in the fig (4-2 b).

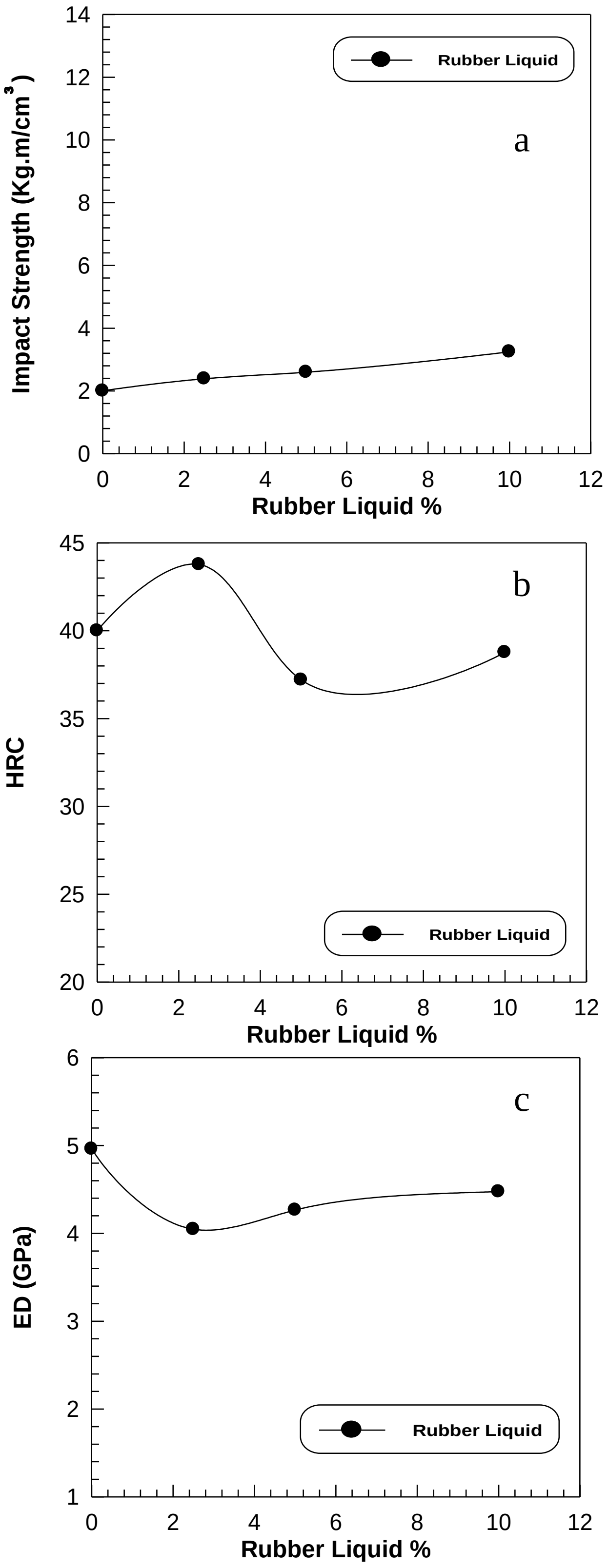


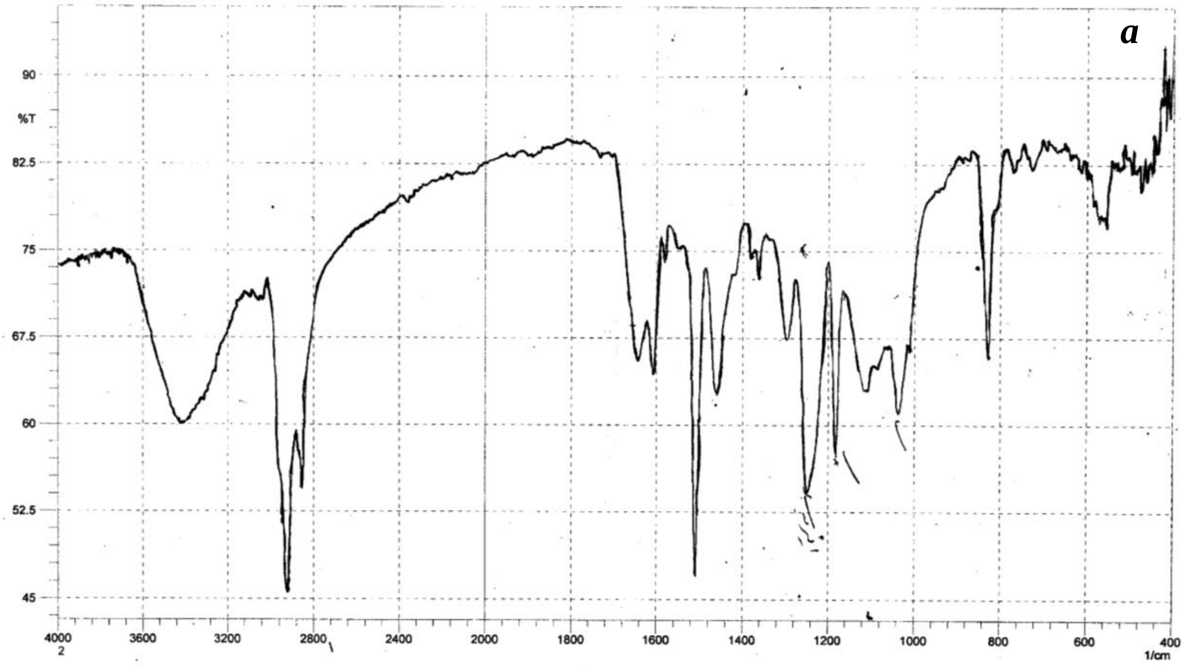
Fig (4-1) effect of rubber liquid percentage on the mechanical properties of epoxy matrix.

a- Impact strength b- Rockwell hardness

c- Dynamic modulus of elasticity.

4.3 Effect of Rubber Liquid percentage on the chemical structure of epoxy

From the observation of the IR spectroscopy for addition 2.5-10 % of rubber liquid figs(4-2b,c,d) and comparison with IR spectroscopy of pure epoxy fig(4-2a)), we observe that the different bonds at (3200 - 3600) cm^{-1} for O.H group and (2800 - 3000) cm^{-1} to (v c-H)aliphatic group and C-H aliphabetic bending at1430 cm^{-1}, C=C at 1500(s) cm^{-1}, C-O-C at 1250 cm^{-1} for epoxy group and can be concluded , there is a creation of a new peak in the band (2400-2000) cm^{-1} and that refer to a new bond is found for △ cyclo propane and that because of the reaction between the rubber liquid series with the epoxy series , also there is shifting in the intensity of all peaks and that due to the constriction in the some of bonds in the new blend because of the chemical interaction between different series , but with a comparison of this curve with the rubber vulcanized powder to the same percentage (2.5) as shown in fig (4-2b,4-5a) we note that non creation of a new peak because of there is no chemical interaction but there is just a shifting in the intensity and that because of the physical interaction and that is due to constitute of a composite material .



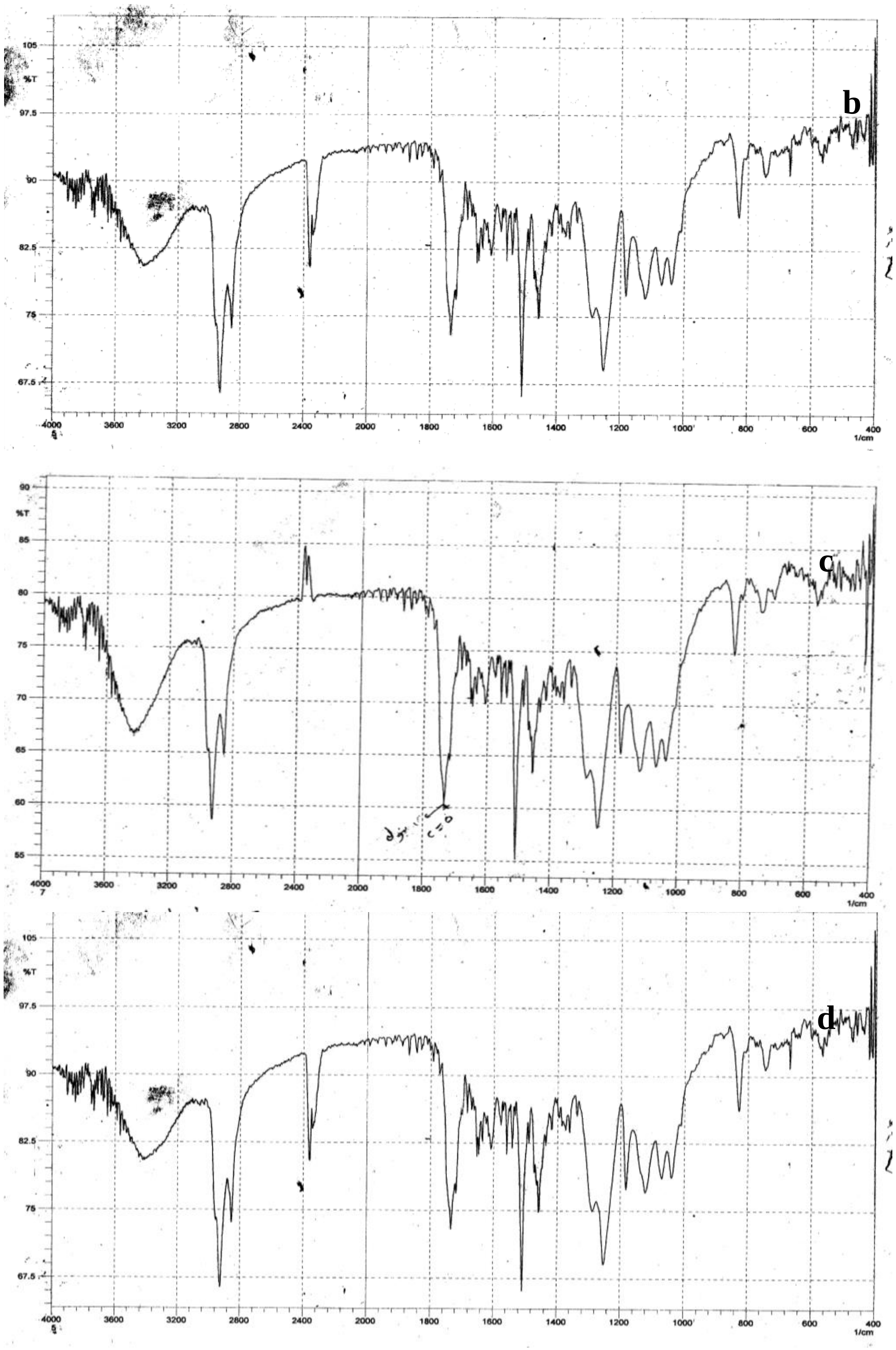


Fig (4-2) effect of rubber liquid percentage on the chemical Structure.

a- Pure epoxy b-2.5% rubber liquid-c-5% rubber liquid d-10% rubber liquid

4.4 Effect of rubber Vulcanized powder on the Mechanical Properties on epoxy

Rubber vulcanized powder used in this work with specification are ,the diameter of rubber particles is typically between (0.5) µm and (5) µm and that a compatible to standard diameter[13] as shown in fig [4-3].

From the observation of fig (4-4,a) can be noted that the behavior of the impact strength will change with values of the rubber vulcanized powder, where the impact strength increases with increasing of the percentage of the rubber powder into value (2.5) after this point, the behavior of the curve decrease until the impact strength value becomes zero, that behavior belongs to improve toughness at low concentrations of rubber particles [13], but high concentration leads to contact the particles with each other and that leads to make the epoxy resin as a strengthening phase instead of the matrix phase and that causes the drop of the toughness of the materials.

A low concentration of the rubber particle can improve the toughness without a significant decreasing is the other properties of polymers such as modulus of elasticity as shown in fig (4-4,c) and the hardness as shown in fig (4-4,b), the curve behavior of the hardness property fig (4-4,b)shows their values are uniform and that belongs to the accumulative or agglomerate of rubber particles in certain sites in the material and that leads to the stability of these values, which are not found in the chemical interactive case as shown in rubber liquid case as shown in fig (4-1,b).

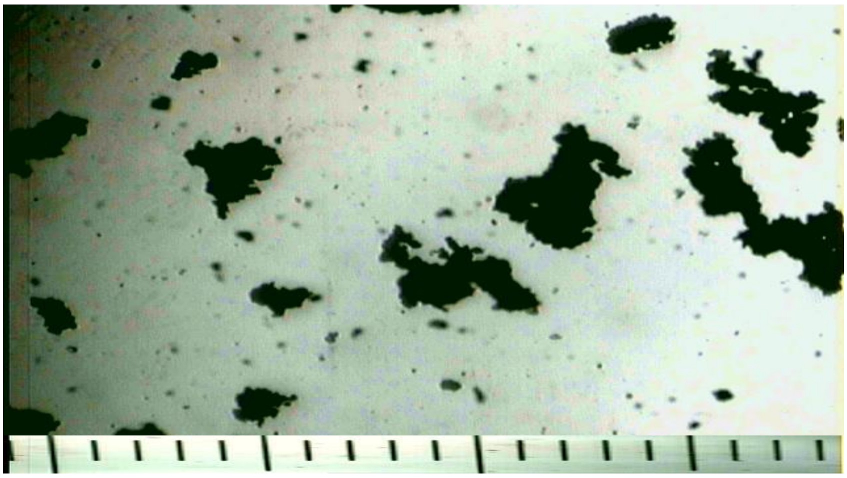


Fig (4-3) microscopic photograph for vulcanized powder of SBR

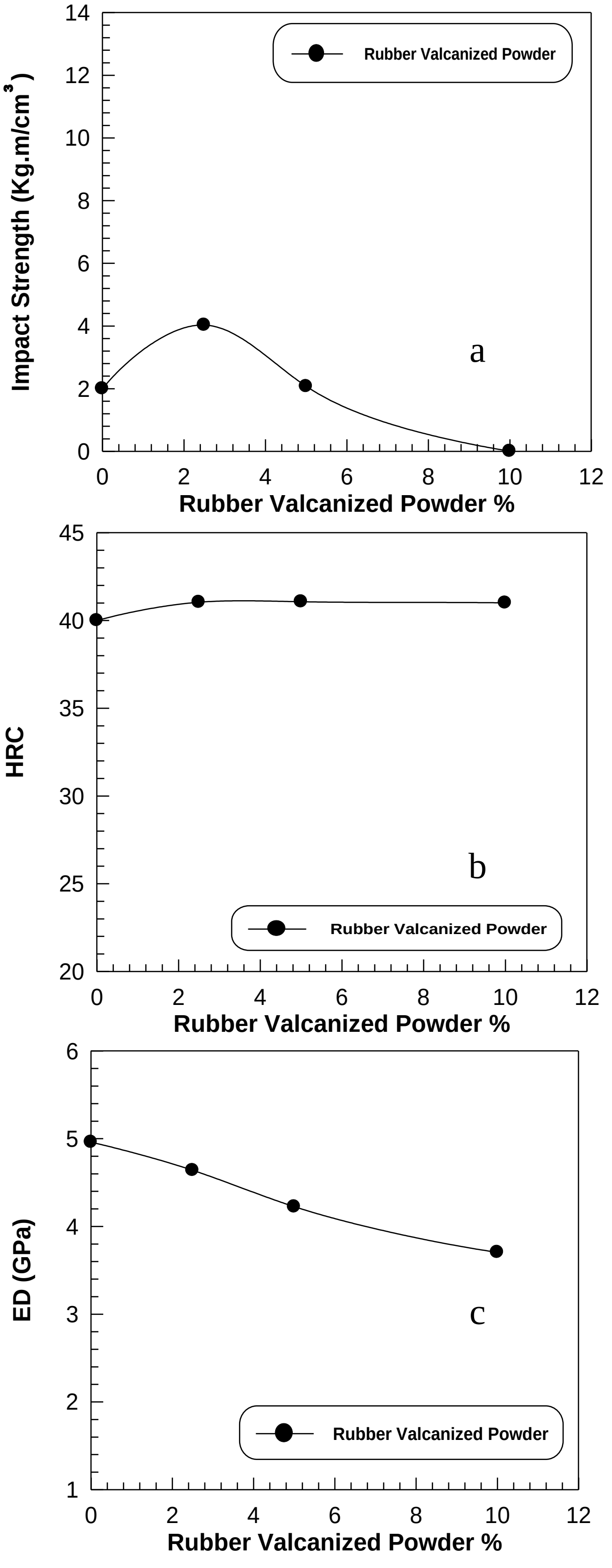


Fig (4-4) effect of weight fraction of rubber vulcanized powder on the mechanical properties of epoxy matrix.

a- Impact strength

b- Rockwell hardness c- Dynamic modulus of elasticity.

4.5 Effect of rubber vulcanized powder percentage on the chemical structure of epoxy:

From the comparison the IR spectroscopy for the pure epoxy fig(4-1a)with the modified epoxy by adding the rubber powder with percentages (2.5 % , 5 % , 10 %) fig (4-5), we observe that the different bonds at (3200 - 3600) cm^{-1} for O.H group and (2800 - 3000) cm^{-1} to (v c-H)aliphatic group and δ C-H at 1470 , C=C at 1600 cm^{-1}, C-O-C at 1250 cm^{-1} for epoxy group ,580 cm^{-1} for-S-.

When comparing these group with the original group of epoxy can be concluded, the difference between the various sample is not clear inspect of the amount of the powder , but there is shafting in the intensity value and that due to the percentage of the rubber powder which are occupied the volume between the epoxy structure .

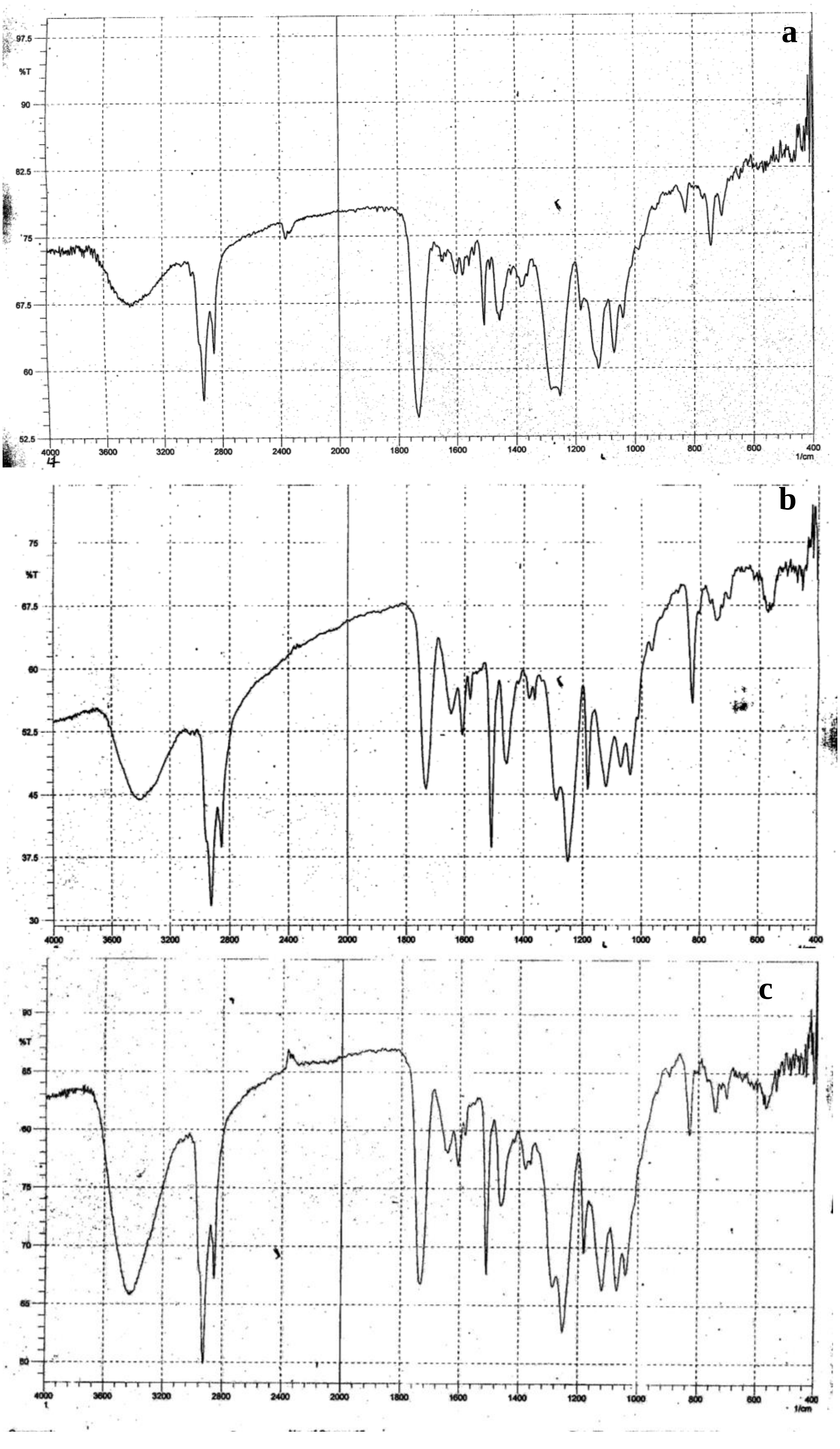


Fig (4-5) effect of weight fraction of rubber vulcanized powder on the chemical structure of epoxy matrix.

a- 2.5% b- 5% c- 10%

4.6 Effect of short fiber weight fraction on mechanical properties

The dispersion of the high concentration of the rubber particle leads to decrease properties of blends; therefore, this problem can be treated by strengthening the blend by using other technique such as a short fiber of the fiber has the toughness property of one hand and ability to adhesive with rubber from other hand and that comfortable in polyamide (nylon 6/6) [1]. This fiber will be coupled agent with rubber material. 0.5 CHF is added to the samples of the prepared blends with the same value of rubber (liquid and vulcanized powder), can be observed that the change of the curve of the impact strength and other properties of the blends is seemed very clear, increasing of the impact strength is clear too. as shown in figs (4-6, a), (4-7, a), but the hardness behavior is different and fluctuated, because of the different in the measured value due to the cavitations and voids in the composite material. While figs (4-6,c), (4-7,c) which shows the dynamic modulus of elasticity for the same value of short fiber in the same percentage of rubber liquid and powder. The difference between the curves is very clear and from the comparison between them can be concluded that the dynamic modulus behavior decreases with increasing of rubber vulcanized powder and liquid, and that belongs to decrease the density of the material (blend) which leads to transmit of the ultrasonic wave from the one side to another in the samples, but the reduction of the dynamic behavior in the case of the rubber vulcanized powder is very sharp when comparing with the liquid addition case and that because of the density values of the rubber vulcanized case which are less density values with the case of the liquid addition and that results from the micro voids and debond and segregation of the rubber particles from the matrix but the density values is higher in the liquid case because of the chemical bonds and absence of voids and high interaction.

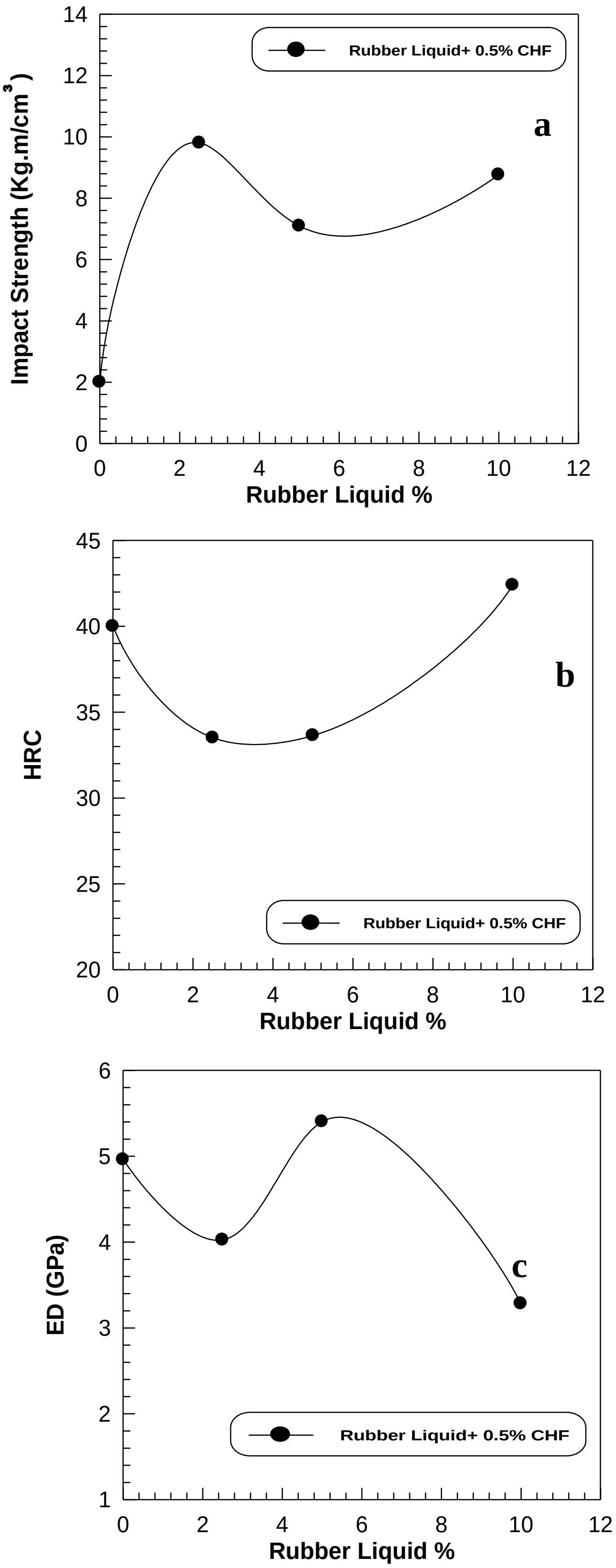


Fig (4-6) effect of short fiber weight fraction on mechanical properties of blends (epoxy + rubber liquid).a- Impact strength b- Rockwell hardness c- Dynamic modulus of elasticity.

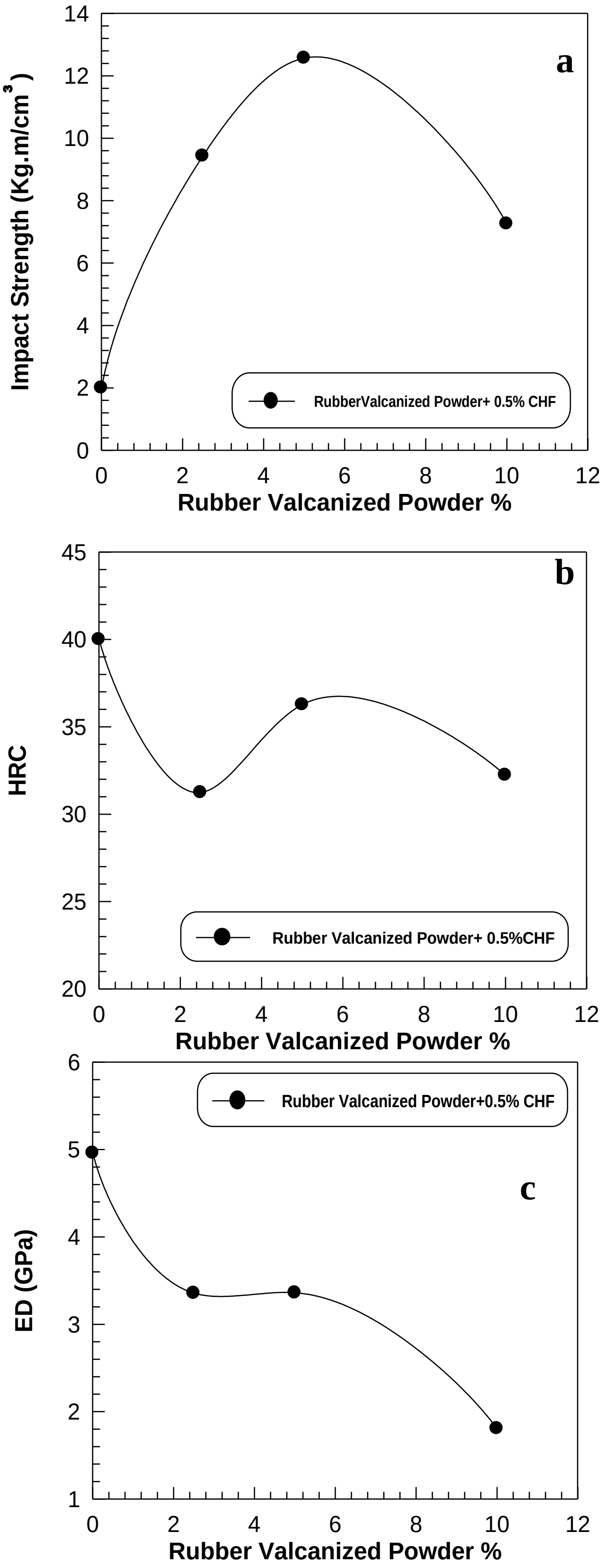


Fig (4-7) effect of short fiber weight fraction on mechanical properties of composites (epoxy + rubber vulcanized powder).a- **Impact strength b- Rockwell hardness c-Dynamic modulus elasticity**

4-7 Discussion of ANSYS Analysis Results

1- Effect of rubber volume fraction on the modulus of the elasticity :

Figures (4-8 a , b) represent the contour distribution for stress and strain , respectively in the elastic range of the compression test model for material M(1).

Figures (4-9 a ,b) represent the contour distribution for stress and strain , respectively in the elastic range of the compression test model for material M (2)

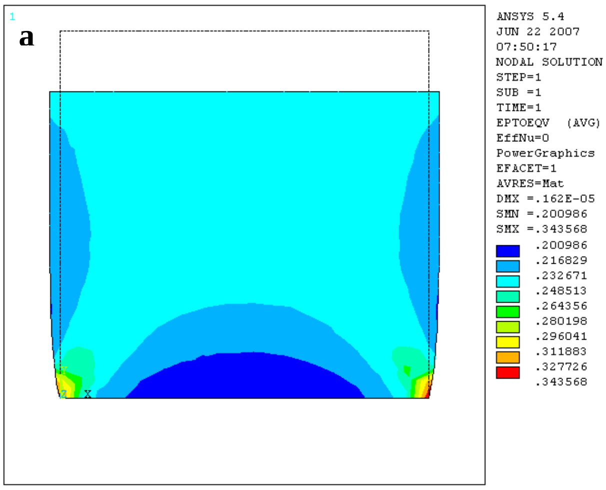
Figures (4-10 a , b) represent the contour distribution for stress and strain , respectively in the elastic range of the compression test model for material M (3)

We can calculate the modulus of elasticity from these results by the ratio between the stress and strain at any point .

The distribution of stress and strain in the fig(4-8a,b) shows the high value of the stress and strain in the base of the sample and near of the edges and that because the constrain base in one hand and the surface tension in the other hand.

The increasing of the volume fraction of rubber which represents by the change of the diameter of the rubber particles as shown in fig (4-8a,4-9a,4-10a) leads to decrease the stresses values in the material particles as seems in blue colour and that was accompanied increasing in the strain value in these sites and that because of the hyper elastic behavior of rubber particle and then the average value of the maximum stress and strain in different volume fractions leads to the different values of modulus of elasticity but the regions between the particle sites(epoxy matrix) suffer from the concentration of stresses and strain as shown in the previous figures because of the brittle behavior of the epoxy specially in the interface between the rubber particles and epoxy.

The FEM results show the modulus of elasticity is decreasing with increasing the volume fraction of rubber addition as shown in fig (4-11 a) and that due to change the behavior of the stress and strain as shown in figs (4-11 b , c) and the contour results for the stress and strain as shown in fig (4-9 , 4-10) , and also is caused from increasing the strain of the rubber chains as show in figs (4-9 b , 4-10 b).



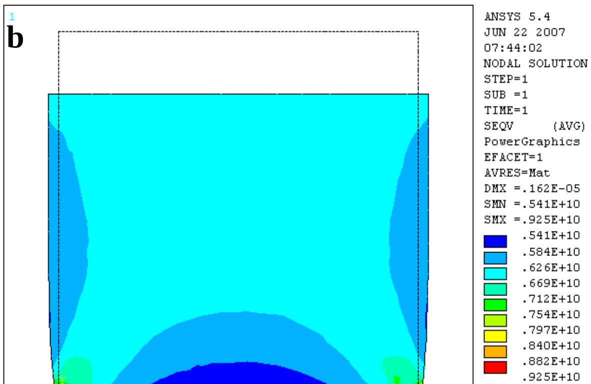


Fig (4-8)numerical results for M(1)

a- stress Von Mises for 0 % volume fraction of rubber

b- strain Von Mises for 0 % volume fraction of rubber

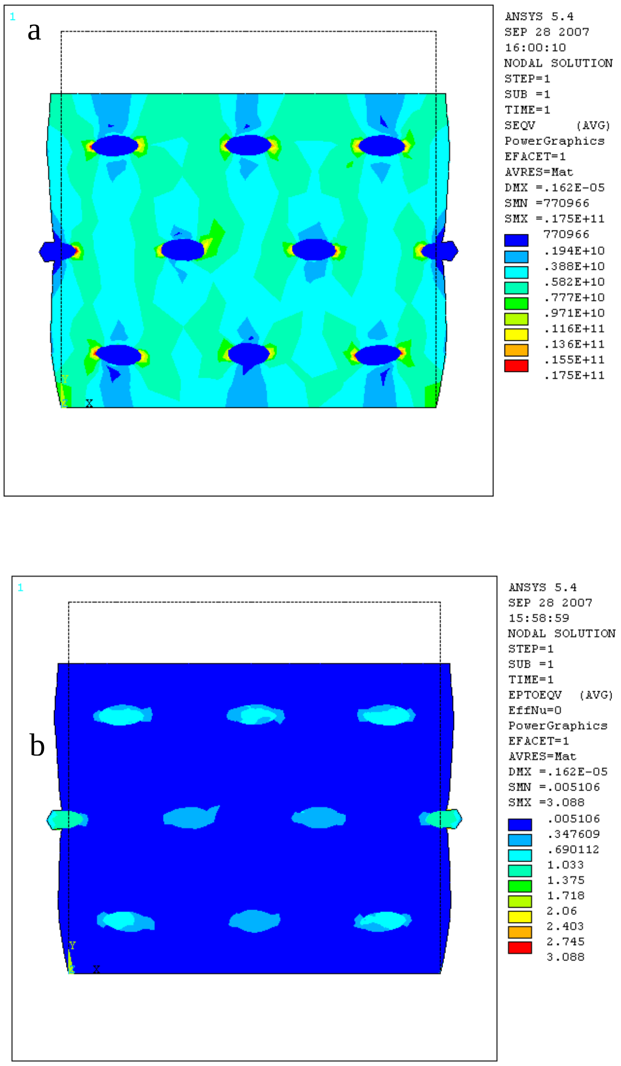


Fig (4-9) numerical results for M(2)

a- stress von Mises for 15 % volume fraction of rubber

b- strain von Mises for 15 % volume fraction of rubber.

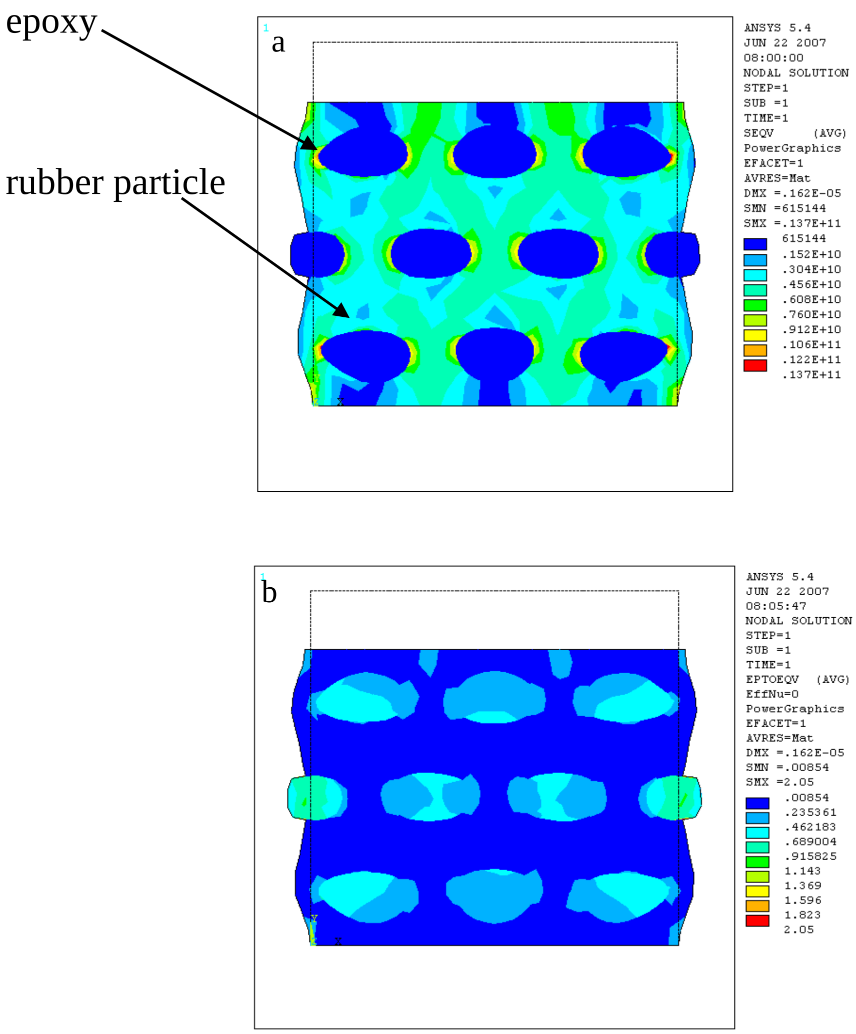
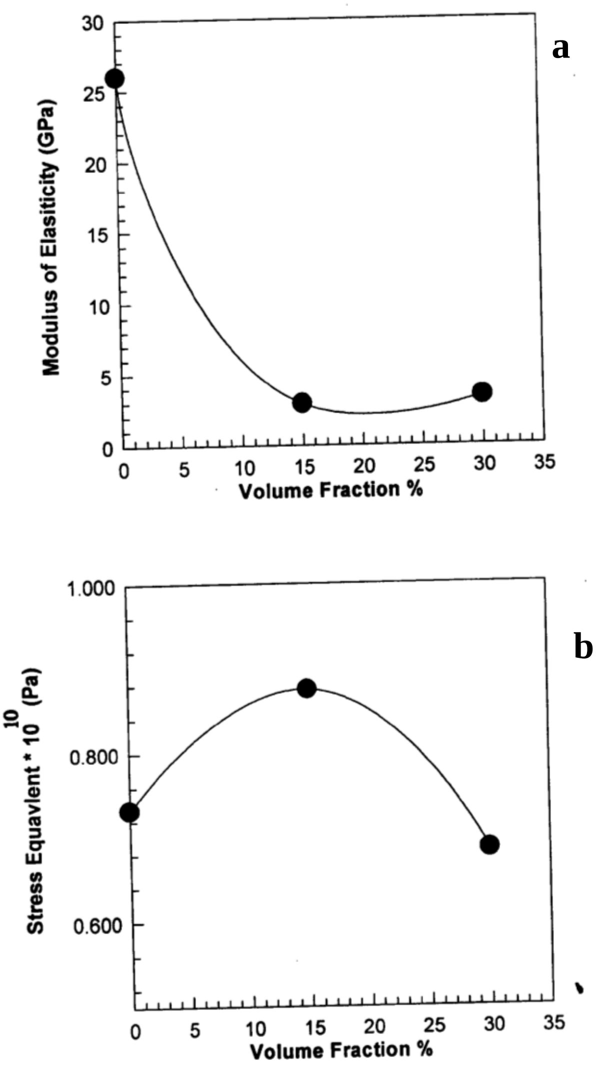


Fig (4-10) numerical results for M(3)

a- stress Von Mises for 30 % volume fraction of rubber

b- strain Von Mises for 30 % volume fraction of rubber



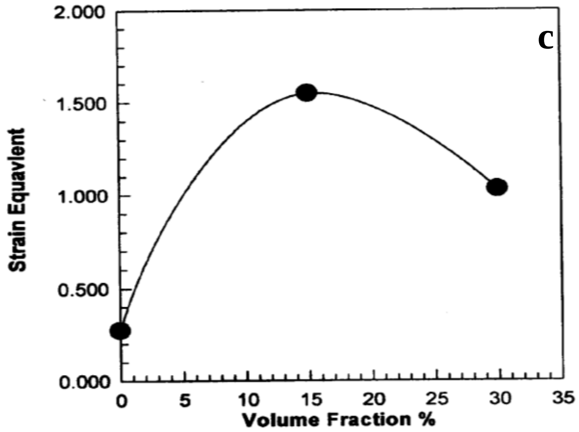


Fig (4-11) Curves of numerical results of modulus of elasticity and stress and strain at specific point of contour model for M_1, M_2, M_3

a-Effect of volume fraction of rubber addition on modulus of elasticity
b-Effect of volume fraction of rubber additives on the stress equivalent .
c-Effect of volume fraction of rubber additives on the strain equivalent .

2-**Efeect of rubber addition on the Toughness property by cracks opening displacement approach** :

From observation the figs(4-12),(4-13),(4-14)which represent the contour result of the stress equivalent around the crack tip with different materials (M 1,M 2 ,M 3), where the modulus of elasticity is used as inlet properties in the modeling process to describe the different materials .The modulus of elasticity is taken from the micro mechanics (compression test) model are (26,2.9,3.37*10^9)Pa respectively .

The results show reduction the stress in this zone with the different material as shown in fig (4-15) and that means the reduction in the plastic zone , which results increasing of the toughness property.

These results agree with the experimented results in behavior as shown in fig (4-1 a , 4-4 a).

The plastic zone prevents the crack propagation due to the crack opening displacement which are resulted by the applied stress (mode I=opening) where the energy is expended in the internal deformation instead of crack initiation.

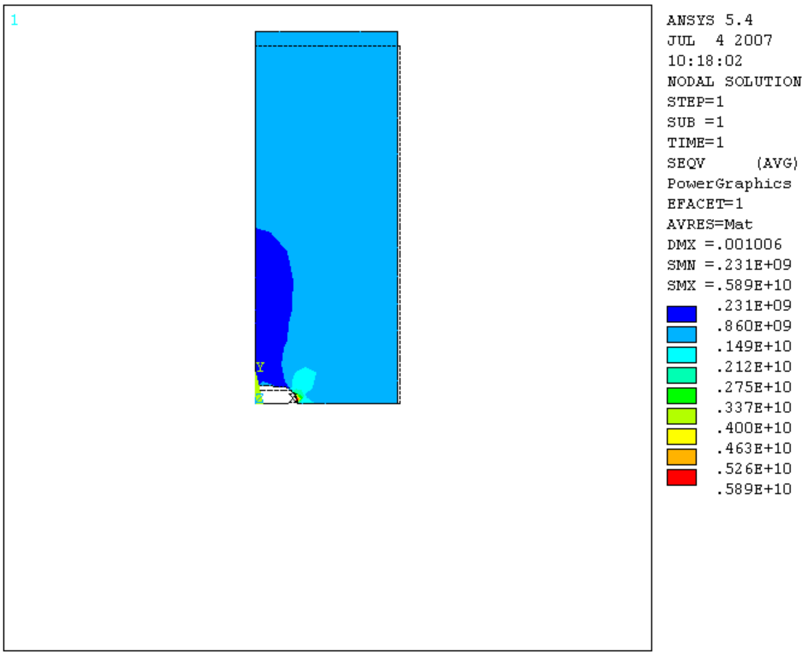


Fig (4-12)The crack opening displacement results of the Von Mises stress around the crack tip of the material which represented (0 % rubber and E= 26×10^{9} Pa)

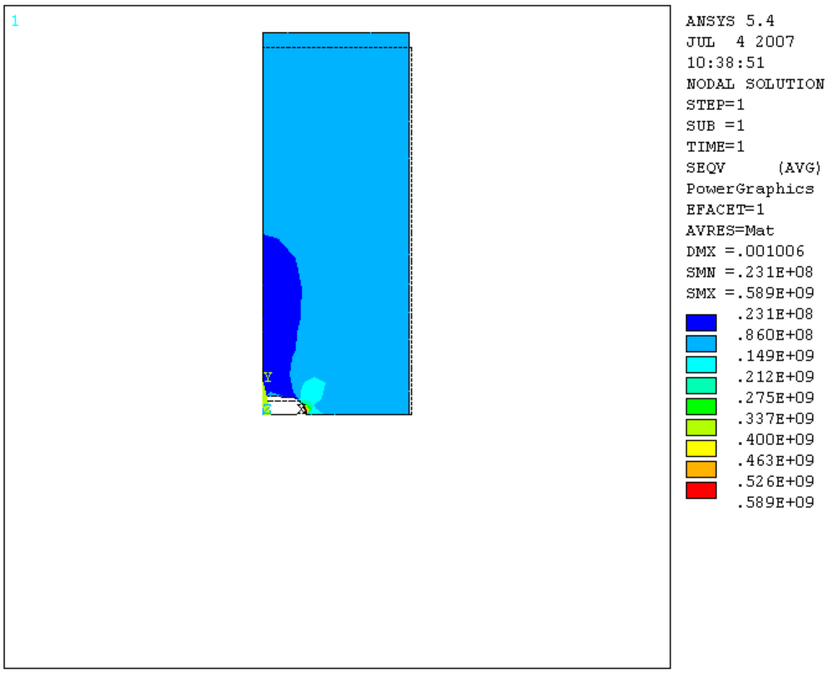


Fig (4-13)The crack opening displacement results of the Von Mises stress around the crack tip of the material which represented (15 % rubber and E= 2.9×10^{9} Pa)

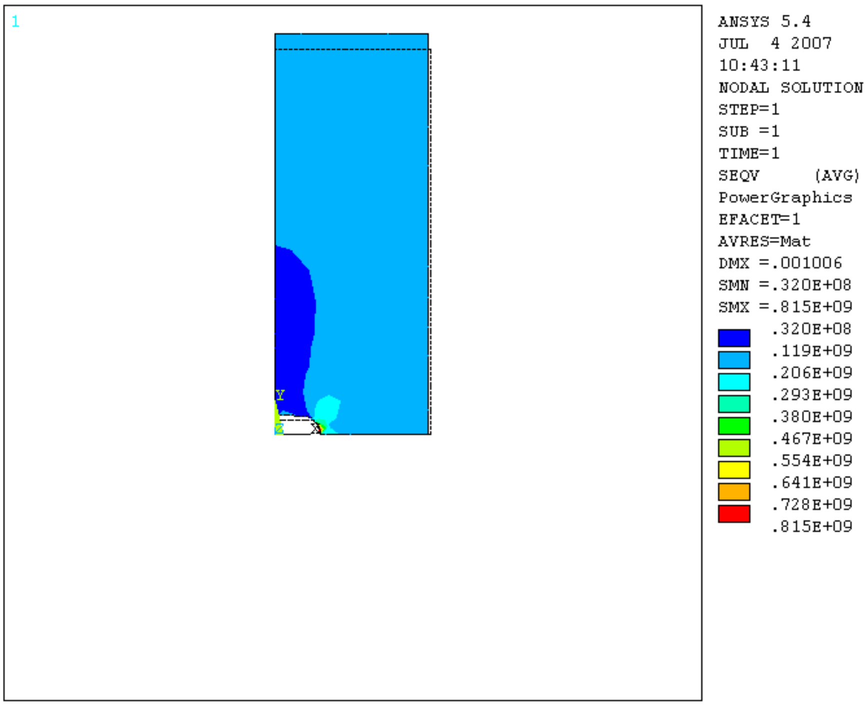


Fig (4-14)The crack opening displacement results of the Von Mises stress around the crack tip of the material which represented (30 % rubber and E= 3.37×10^{9} Pa)

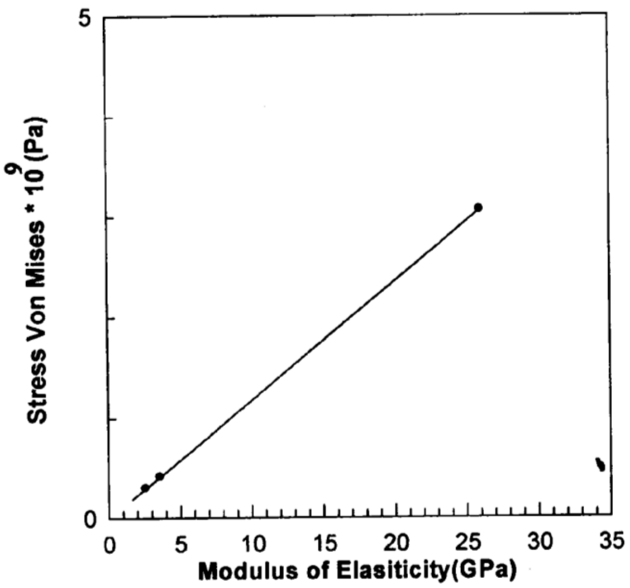


Fig 4-15 the relationship between modulus of elasticity for M_1, M_2, M_3 and stress Von Mises .

Chapter five
Conclusions and recommendations

5-1 *conclusions*

From the theoretical analysis of rubber additives to the epoxy and the comparison with experimental results for the effect the same parameter which are studied in the theoretical analysis we are conclude the followings:

1- The low concentration of the rubber additives(0-2.5%) is improved and kept the other properties of the blend in the confident values.
2- The rubber liquid technique is the best than rubber vulcanized technique in the prepared blend, but rubber vulcanize technique is the best with the short fiber.
3- The addition of the short fiber leads to improve the toughness property and increase the spesific strength.
4- Micro mechanics model is active to predict the toughness behavior with increasing the percentage of the rubber particle (liquid or powder).
5- Macro mechanics models (crack opening displacement) are active to predict the effect of rubber additives on the impact strength and on the other properties of blends.
6- The theoretical analysis is agreed with the experimental work to acceptable value.

5-2 *recommendations and suggestions*

The following recommendation for further work are:

1. This work related to one type of thermoset and it is possible to use another types of resins as a matrix and use another type of reinforcement.

1. Studying the electrical and optical properties for binary blends in the current work and their composites.
2. Studying effect of environment al properties (ultraviolet, humidity and temperature degree) on blends and composites.
3. Studying the chemical resistance the of blends and composites.
4. Studying effect of thermal aging on mechanical properties of blends and composites.
5. This work can be extended to study the effect of rubber type on blends and composites.
6. Using ANSYS system to calculate the vibration on material.
7. Using other toughening technique for epoxy on ANSYS system.
8. Studying the mechanical behavior by assuming change volume fraction instead of assumed it constant as done in this work.
9. Reinforcement the blends and composites of continuous fiber instead of chopped fibers and studying effect of difference of fiber orientation on mechanical properties.

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