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Mechanical Properties of Composite Material Using Natural Rubber with Epoxy Resin

Dr. Hani Aziz Ameen*

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Abstract

In this paper the mechanical properties of three types of composite materials using natural rubber vulcanized, unvulcanized and reinforced rubber have been investigated . The composite material using natural rubber and epoxy resin is manufactured by three methods, first method is mixing the natural rubber with epoxy resin by special mixer without any additional materials, the second method is to make a layer of rubber then coating it with a layer of epoxy resin and bonding using the rolling process. The third one is use in the natural rubber as a matrix material and using additional materials like carbon black in specific ratio and mix with them the epoxy resin in five ratios (20%, 40%, 60%, 80%, and 100%) .

The first and second methods failed because composite material produced was inhomogeneous while the third method succeeded and the composite material was homogenous. Compression and hardness tests have been done on the resulting composite material of the third method and from the result it is found that the composite material has good properties and these properties improved by increasing the ratio of epoxy resin to the natural rubber. Then the mechanical properties of three types of composite material using natural rubber vulcanized, unvulcanized and reinforced rubber have been investigated . Each type was coated with six percentages of epoxy resin (0% , 20% , 40%, 60%, 80%, and 100 %) . The values of Young's modulus, yield stress, tensile strength and yield strain which were calculated for each case and for all percentages of epoxy resin. It is concluded that the properties of the new composite material using natural rubber is muchbetter than the properties of the pure natural rubber and the increasing in the percentage of epoxy resin in vulcanized rubber leads to a decrease in Young's modulus and increasing percentage of epoxy resin in unvulcanized rubber and reinforced rubber leads to an increase in Young modulus.

Keywords: Composite Materials, Natural Rubber , Epoxy Resin, Engineering materials

الخلاصة

في هذا البحث تم دراسة الخواص الميكانيكية للمادة المركبة الناتجة من اضافة راتينج الايبوكسي الى عجنة المطاط الطبيعي في ثلاث حالات حيث تم تصنيع المادة المركبة باستعمال المطاط الطبيعي ومادة الايبوكسي وتم صنع العينات بثلاث طرق . الطريقة الاولى كانت بخلط المطاط مع الايبوكسي بدون اي اضافات باستعمال خلاطة خاصة . والطريقة الثانية كانت بجعل المطاط على شكل طبقات مغطاة بالايبوكسي ومن ثم اجريت عليها عملية الدرفلة . الطريقة الثالثة هي باستعمال المطاط الطبيعي كمادة اساس ثم استعمال مواد اضافية كالكاربون وغيرها من المواد

*Technical College / Al-Musaib – Pumps Eng. Dept.

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University of Technology-Iraq, Baghdad, Iraq/2412-0758

وبنسب معينة واضافة الايبوكسي بخمس نسب (٢٠% ، ٤٠% ، ٦٠% ، ٨٠% و ١٠٠%) . الطريقة الاولى والثانية فشلت لان المادة الناتجة كانت غير متجانسة ، بينما المادة المستحصلة في الطريقة الثالثة كانت متجانسة ومتماسكة . وقد تم اجراء اختبار الضغط والصلادة على نماذج من المادة المركبة المستحصلة بالطريقة الثالثة وقد وجد انها ذات خواص جيدة وان خواصها تتحسن بزيادة نسبة الايبوكسي الى مادة المطاط . وكذلك دراسة الخواص الميكانيكية اذ تم تحضير المادة المركبة من اضافة راتينج الايبوكسي الى عجنة المطاط الطبيعي في ثلاث حالات . الحالة الاولى اضافة الايبوكسي الى عجنة المطاط الطبيعي الغير المفلكنة اي غير معرضة لظروف الفلكنة من ضغط ودرجة حرارة وبكل النسب (٢٠% ، ٤٠ % ، ٦٠% ، ٨٠% و ١٠٠ %) بالاضافة الى الحالة القياسية ، والحالة الثانية عرضت الى ظروف فلكنة قياسية وبكل النسب المبينة بالاضافة الى الحالة القياسية . اما الحالة الثالثة فقد كانت بتقوية العينات وتسليحها بخيوط من الكتان الخاصة بالمواد المطاطية وبكل النسب ايضا . حيث تم دراسة الخواص الميكانيكية ومدى تأثرها باضافة راتينج الايبوكسي اليها ودراسة قيم معامل المرونة واجهاد الخضوع وانفعال الخضوع.

تم تحليل النتائج التجريبية التي حصل عليها من التجارب المختبرية لغرض الوصول الى اختيار افضل للنتائج وقد لوحظ بان معامل المرونة يقل في الحالتين الاولى والثانية ويزداد في الحالة الثالثة بزيادة نسب الايبوكسي.

Introduction

Natural rubber is a heavily researched material, in which the modern technologies require materials with usual combinations of properties that can not be met by the polymeric material. Black et al [1] expanded the relationship between the natural rubber structure and thermal aging to include physical properties. Reinhart et al [2] demonstrated that the epoxy resin are used extensively in the composite materials for a variety of demanding structure requirements. Sloan [3] has investigated the effect of carbon black on natural rubber. In this paper the new composite material using natural rubber with epoxy resin is investigated , the natural rubber isused as a matrix material and epoxy resin and carbon powder as the reinforcement material .

Rubber because of its elasticity is in many respects a unique phenomenon, involving properties markedly different from those of low – molecular – weight solids, liquids or gases. Epoxy resins are used as adhesives and coatings and can be used in both molding and laminated techniques to make articles with better mechanical strength [4]. Neogi et al [5] have researched the high temperature interaction between rubber and filler by using stain amplification factor. Wang [6] found that the modulus of the compound increases with the increasing level of carbon black. Fleischman [7] explains the theory of rubber elasticity as beiy based upon an irregular , three dimensional network. It is clear that there are many literatures dealing with the composite materials but limited literatures investigated the rubber technology, therefore this paper concentrated on this subject using the natural rubber and epoxy resins.

Manufacturing the Composite Material

Three methods are used for manufacturing the materials is :-

1-The first method by mixing the natural rubber with epoxy resin only without adding any materials using special mixer as shown in Fig.(1) The result from this process is inhomogeneous and disintegrated materialan. Then the rubber is completely disintegrated and nothing obtained from this method.

2-The second method is to treat the natural rubber alone in the mixer and then pass it through rolling process in the special rolling machine as shown in Fig.(2) to obtain a layer of natural rubber in thickness about (1mm) , then manufacturing the material layers after coating by epoxy layers , the composite sample is formed of three layers of natural rubber and two layers of epoxy resin , this method also fails because the layers of natural rubber shows tearing,and is inhomogeneous and full of holes and cavities as shown in Fig.(3).

3-In the third method, the matrix material used is natural rubber which prepared previously by special mixer (Fig.(1)) and aed some of agent materials are added in limited percentages according to standard reference Maurice Morton[8].and as follows:

a-Dutrex Oil

A small amount may be added to control and standardize the viscosity of the individual's batches.

b-Stearic Acid

A small amount of stearic acid has long been standard addition to natural rubber mixers to assist the action of acceleration and serve similar purpose in most sulphur vulcanizabled rubber, it also aid processing by exerting a plasticizing action and reducing the tendency.

c-*OBTS,NOX,IPPV(vulcanize agents)*

In combination with vulcanizing agents, these materials reduce the vulcanizing time (curve time) by increasing the rate of vulcanization in most cases , the physical properties of the products are also improved.

d- Sulphur (vulcanize agent)

This materials is necessary for vulcanization since without, the chemical crosslinking reactions involving these agents no improvement in the physical properties of the rubber mixes are obtained.

e- Zinc Oxide

The rubber industry zinc oxide is second in importance only to sulphur Without zinc oxide most organic accelerators will not function propert. Zinc oxide will be found in almost every compoundly for activation of accelerators.it is added on a small amount of 2 or 3 parts of zinc oxide per 100 parts of rubber .

f- Paraffin wax

It acts as a softener , and helps processing by reducing adhesion to mill and rolling , blooming to the surface, protects the surface against ozone , and to reduce attack by chemicals such as oxidizing agents[9].

Composite Material Preparation

The steps of composite material preparation are explained below:-

1-Prepare the materials which must be dough in the mixer according to the following quantities for 300gram , as shown in table(1) :

Table(1) Dough's contain

Material Name	**Quantity (gram)**
Natural rubber	178.65
Carbon black	90.75
Dutrex oil	12.2
Zinc oxide	7.15
Stearic Acid	3.57
OBTS	2.719
Sulphur	3.007
NOX	1.776
IPPV	2.98
Paraffin wax	3.578

1-The resin and hardener are mixed at room temperature (25 °C) at a ratio 2:1 according to weight , the mixing process is continued for (15 minutes) until the mixture homogenous and its temperature is raised.

2-Natural rubber which is prepared previously by special mixer was mixed with carbon black and epoxy resin different percentages (20% , 40% , 60%, 80% and 100%) from the filler (carbon black) and put in mixer, the mixing process was continued for 5 minutes until the mixture becomes homogenous.

3-The dough was passing across in rolling process (Fig.(2)) by two different speed rollers to produce a sheet with thickness about (2mm).

4-This sheet was left for about (24 hours) at room temperature (25°C) to obtain the optimum state for dough.

Compression Test

The compression test specimen has been produced according to (ASTM-D395-78) as shown with the standard dimensions in Fig.(4) where the length to diameter ratio is approximately 1:2 .

Table(2) gives the results of compression set by the constant deflection for the standard vulcanize rubber and five percentage of epoxy resins which added to the natural rubber (20% , 40% , 60%, 80% and 100%) according to the equation below [10] :

$$C = \left(\frac{t_o - t_i}{t_o - t_n} \right) x100 \quad \text{...........(1)}$$

where:

C = compression set expressed as percentage of the original deflection.

t_o = original thickness of specimen.

t_i = final thickness of specimen.

t_n = thickness of spacer bar used.

Table(2) Compression set of vulcanized rubber specimens

Percentage of epoxy	***Compression set (C) %***
Standard (0%)	45
20% epoxy	75
40% epoxy	140
60% epoxy	165
80% epoxy	175
100% epoxy	180

Table(3) shows the results of compression set by the constant deflection for the standard unvulcaniz

ed rubber and five percentages of epoxy resins which an added to the natural rubber (20%, 40%, 60%, 80% and 100%) according to equation(1) .

Table(3) Compression set of unvulcanize rubber specimens

Percentage of epoxy	***Compression set (C) %***
Standard (0%)	200
20% epoxy	190
40% epoxy	170
60% epoxy	150
80% epoxy	120
100% epoxy	110

Hardness Test

The hardness test is done with instrument called " Shore Durometer" as shown in Fig.(5) the reading depends on the degree of penetration. Table(4) shows the values of hardness test to the vulcanized rubber in different percentage of epoxy resin (20% , 40% , 60%, 80% and 100%) .

Table (4) The values of the hardness test to the vulcanized rubber

Percentage of Epoxy	***Hardness Rate***
Standard (0%)	62
20% epoxy	70
40% epoxy	81
60% epoxy	87
80% epoxy	92
100% epoxy	95

Table(5) shows the values of hardness test to the unvulcanized rubber in different percentage of epoxy resin (20%, 40%, 60%, 80% and 100%) .

Table (5) The values of the hardness test to the unvulcanized rubber

Percentage of Epoxy	***Hardness Rate***
Standard (0%)	25
20% epoxy	32
40% epoxy	52
60% epoxy	55
80% epoxy	72
100% epoxy	74

Load-Extension and Stress – Strain Curves

Tensile test is one of the most used method for determining the modulus of elasticity, yield tensile stress , yield strain, ultimate strength and ductility of material. The test involves an axial tensile load being applied to a standard specimen of rectangular cross- section Fig.(6), with a constant strain rate at about (100 mm/min) by hydraulic tensile device shown in Fig.(7) and this causes the specimen to elongate and finally fracture Fig.(8).

1- Tensile Test for Vulcanize Composite Material Specimen.

The behavior of rubber when stretched constitutes, one of the most important methods to investigate its physical properties. The common procedure is to stretch the rubber at a fixed and uniform rate, when expressed graphically the load which is applied and the elongation in the x-y axis (Fig(9)).

The curve may be divided into three parts. First section concave toward the elongation axis showing that the elongation here increases more rapidly than load or stress. The second section of the curve is substantially straight whilst the third section is concave in the opposite direction to the first section. in the second section the load is increasing more rapidly than the elongation because of changes brought about in the rubber through stretching, in this case the crystallization in the natural rubber occurs, finally the rubber breaks.

Fig(9) and Fig.(10) make a comparison among all the percentages of epoxy (20% , 40% , 60%, 80%, and 100%) with the standard curve [8],[9] to show the differences among them. These explaind that the stress and load are decreasing ; also strain and elongation are decreasing as well as the percentage of epoxy resin.

Table(6) shows the values of the Young Modulus , Yield tensile stress, yield strain , yield load and yield elongations are determinate for all cases.

2- Tensile Test for Unvulcanized Composite Material Specimen

For unvulcanized rubber the general shape of the curve is approximately similar but the behavior is much more susceptible to changes in the test conditions than with vulcanized rubber. At increased temperatures the elongation at break of unvulcanized rubber is greatly increased and the tensile strength is slightly reduced.

Fig.(11) & Fig.(12) show differences among variable percentages of epoxy (20% , 40% , 60%, 80%, and 100%) added to unvulcanized rubber and these refer to increasing in the stress and load against decreasing in strain and elongation.

Table(7) shows the values of the Young modulus , yield tensile stress, yield strain, yield load and yield elongations are determinate for all cases.

3- Tensile Test for Reinforcement Composite Material Specimen

The specimen is reinforced by flax threads (the tensile strength for the flax threads alone was measured of 20.5 N/mm^2). Fig(13) & Fig(14) show the difference among variables percentages of epoxy (20% , 40% , 60%, 80% and 100%) added to reinforced rubber, there refer to increasing in the stress and load against decreasing in strain and elongation.

Table(8) shows the values of the Young modulus , yield tensile stress, yield strain , yield load , and yield elongations are determinated for all cases.

Discussion

Three methods are used to manufacture the composite materials , the first and second were failed and the third one was passed , and can be vulcanize and/or reinforcement by flax threads for each percentage of epoxy . The compression test and hardness test have been done to find the influence of adding the epoxy resin to the natural rubber in which the compression is increased when increased the percentage of epoxy resin in case of vulcanize rubber , but in case of unvulcanized rubber the compression is decreased when the percentage of epoxy resin increased, and the hardness rate when the percentage of epoxy resin are increased for both vulcanized and unvulcanizd rubber, and this means that the hardness property of the natural rubber is improved when the epoxy resin is added .

Conclusions

The main important conclusions which can be drawn from this work are:

1-Particular composite of natural rubber with epoxy resin is a new composite material which can be used for different fields.

2-Compression set for natural rubber with epoxy resin is increased as increased the percentage of epoxy resin is in vulcanized rubber and decreases as increasing the percentages of epoxy resin in unvulcanize rubber are increased.

3-The hardness of composite material is improved when the epoxy is added to it .

The main important conclusions that can be drawn from this work are as follows:

1-Increasing percentages of epoxy resin in the vulcanize rubber leads to a decrease in Young’s modulus for tensile test .

2-Increasing percentages of epoxy resin in the unvulcanize and reinforced rubber leads to a increase in Young’s modulus for tensile test .

3-Yield stress for natural rubber with epoxy resin is decreased as increasing of percentages of epoxy resin in vulcanize rubber for tensile test.

4-Yield stress for natural rubber with epoxy resin is increased with increase in percentages of epoxy resin in unvulcanized rubber for tensile test.

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Table (6) The determination of tensile values for vulcanized rubber

Percentage of epoxy	Young Modulus N/mm^2	Yield tensile stress N/mm^2	Yield strain	Yield load N	Yield elongation mm
Standard %	4.8769	5.1333	204.6	61.6	89.389
20 % epoxy	3.495	4.9415	170.8	56.3	88.522
40 % epoxy	2.2009	4.6458	100.14	31.75	40.056
60 % epoxy	1.4712	4.5250	11.816	30.3	18.7265
80 % epoxy	1.2610	4.3167	15.206	31.8	16.0825
100 % epoxy	1.2405	4.0111	13.653	26.133	13.461

Table (7) The determination of tensile values for unvulcanized rubber

Percentage of epoxy	Young Modulus N/mm^2	Yield tensile stress N/mm^2	Yield strain	Yield load N	Yield elongation mm
Standard %	0.8382	0.654	16.372	10.30	5.490
20 % epoxy	1.8083	1.153	10.343	9.70	4.137
40 % epoxy	2.2029	1.178	10.510	8.50	4.2040
60 % epoxy	2.9986	1.188	9.077	6.10	3.2310
80 % epoxy	3.1883	1.254	8.783	5.10	3.9130
100 % epoxy	3.9444	1.282	5.635	4.10	2.2540

Table (8) The determination of tensile values for Reinforced rubber

Percentage of epoxy	Young Modulus N/mm^2	Yield tensile stress N/mm^2	Yield strain	Yield load N	Yield elongation mm
Standard %	36.49	17.156	25.793	128.80	10.317
20 % epoxy	37.96	18.789	51.982	338.2	20.793
40 % epoxy	38.88	19.194	52.067	345.5	20.827
60 % epoxy	39.26	20.544	53.773	343.80	25.510
80 % epoxy	43.17	24.522	58.345	461.80	27.338
100 % epoxy	45.12	27.472	59.443	466.5	31.777

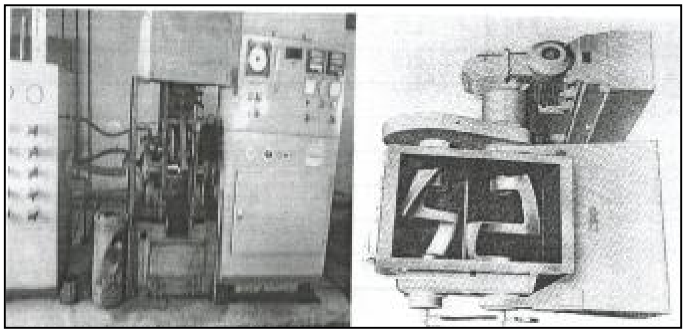
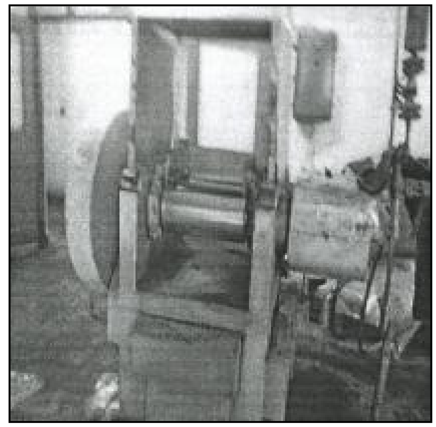
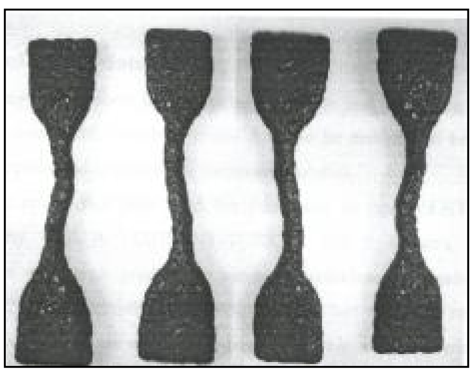


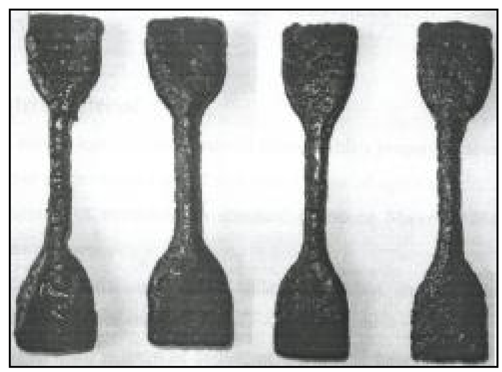
Fig.(1) Mixing device of natural rubber



Fig(2) Rollers machine

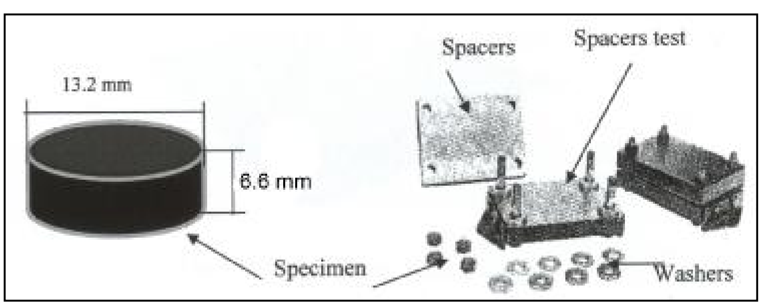


a- Sample by layers without reinforcement

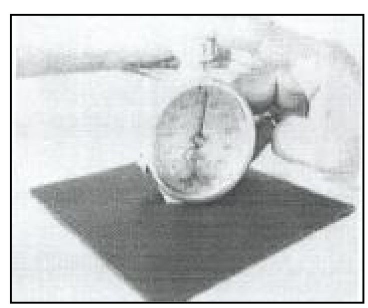


b- Sample by layers with reinforcement

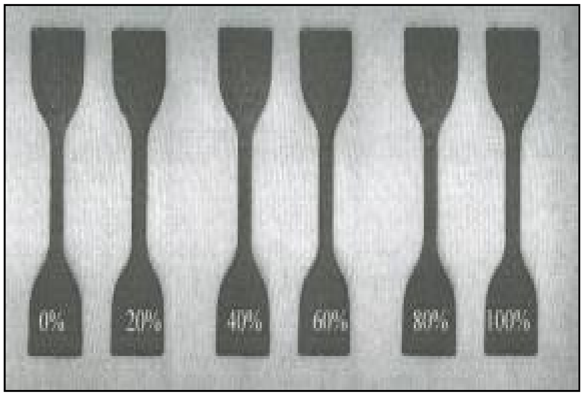
Fig(3) Failed samples



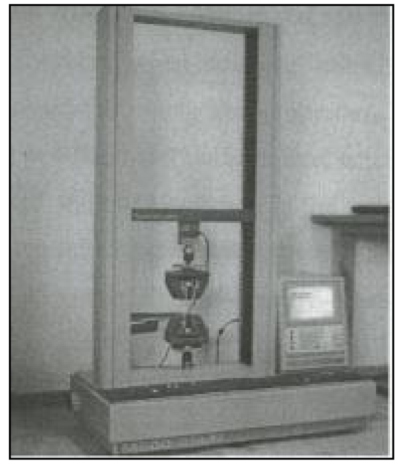
Fig(4) Components of compression device



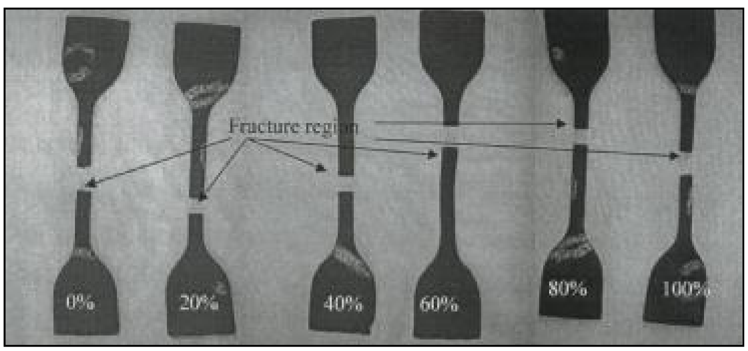
Fig(5) Shore durometer



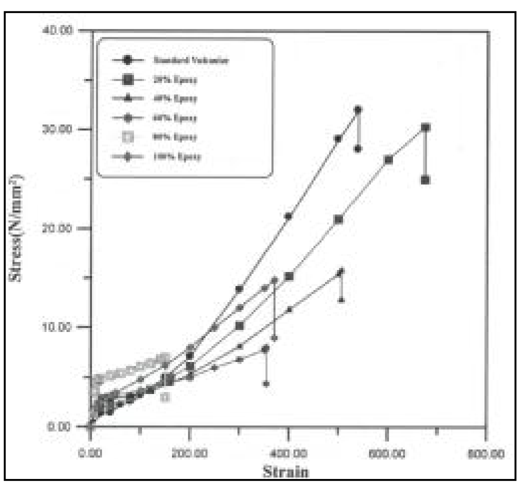
Fig(6) Tensile specimens



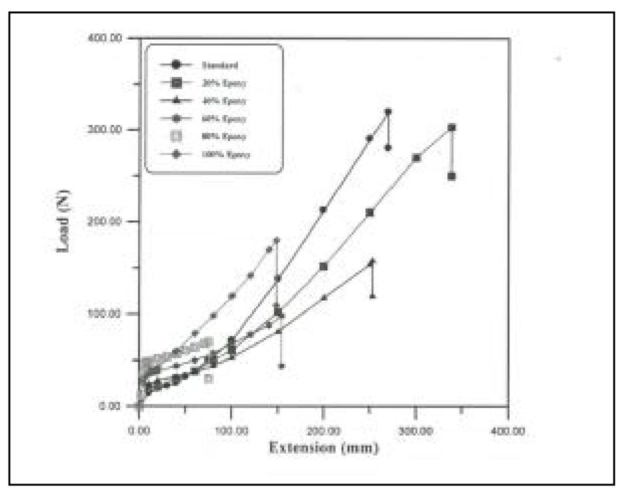
Fig(7) Computerized test meter



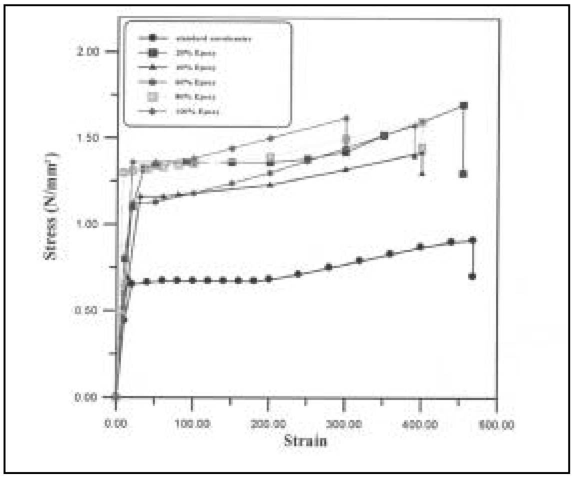
Fig(8) Tested specimens



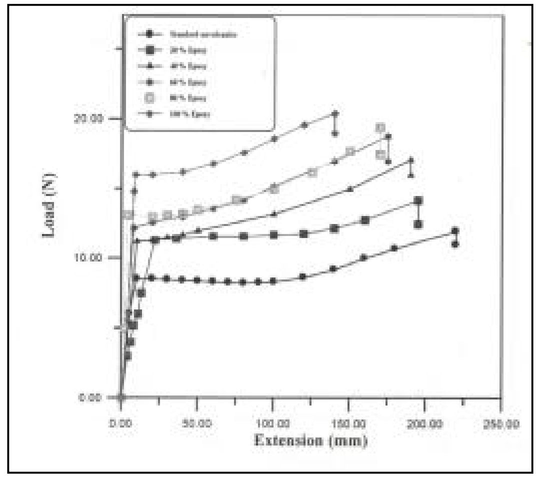
Fig(9) Comparim Stress-Strain Curve for standard vulcanized rubber with curves of all percentages of epoxy



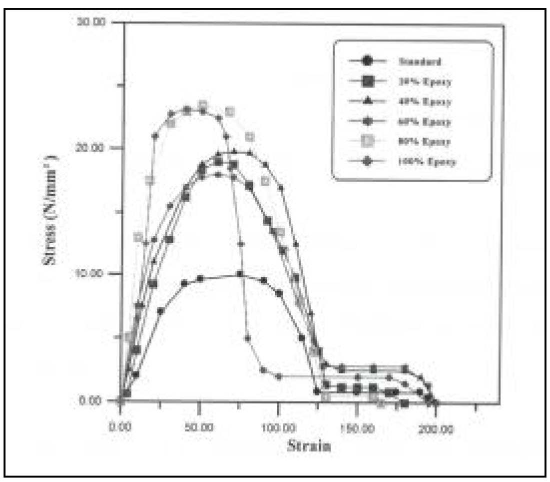
Fig(10) Comparising Load-Extension Curve for standard vulcanized rubber with curves of all percentages of epoxy



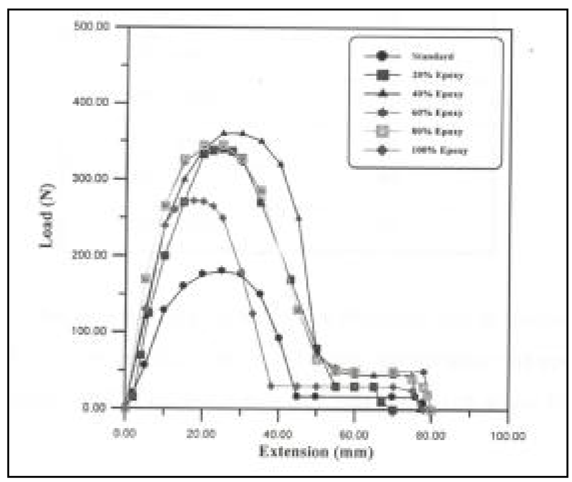
Fig(11) Comparising Stress-Strain Curve for standard unvulcanized rubber with curves of all percentages of epoxy



Fig(12) Comparising Load-Extension Curve for standard unvulcanized rubber with curves of all percentages of epoxy



Fig(13) Comparising Stress-Strain Curve for standard Reinforced rubber with curves of all percentages of epoxy



Fig(14) Comparising Load-Extension Curve for standard Reinforced rubber with curves of all percentages of epoxy