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Polymeric Additives Effect on Mechanical Properties for Bitumen Based Composites

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Abstract

Bitumen binder is a thermoplastic liquid and the elementary analysis of the bitumen manufactured from a variety of crude oils shows that most bitumen contains carbon, hydrogen, sulphur, oxygen, and nitrogen. At high temperature or low loading, it behaves as a viscous liquid. This classical dichotomy creates a need to improve the performance of an asphalt binder to minimize the stress cracking that occurs at low temperatures and the plastic deformation at high temperature. In order to increase the durability of bitumen materials are needed to modify the quality of bitumen materials. The research work covers five percentages of thermoplastic copolymer content (5%, 7%, 9%, 11%, and 13%) by weight of bitumen were used. The polymer modified mixes were designed in accordance with Marshall Test. Experimental testing has revealed the enhancement in the physical and mechanical properties of bitumen mixtures when the five percents of the thermoplastic copolymer were added. The ethylene vinyl acetate (EVA) modified bitumen had the lowest penetration and highest kinematic viscosity as compared with that of unmodified bitumen. The ethylene vinyl acetate (EVA) modified mixtures also has experienced the highest Marshall Stiffness, indirect tensile strength and unconfined compressive strength as compared with that of unmodified mixtures. The experimental results are used to develop four empirical correlations. The practical use of such equations, given the value of the mechanical properties with the polymer and bitumen content without needs any experimental data points.

Keywords: indirect tensile strength, bitumen, copolymer-bitumen mixture, mechanical properties of bitumen, Marshall Stiffness

تاثير الاضافات البوليمرية على الخواص الميكانيكية لمادة البيتويومان

الخلاصة

المادة المستخدمة لغرض التبليط هي من المواد المطاوعة للحرارة واغلب العناصر المكونة لهذة المادة هي الكاربون ,الهيدروجين,الكبريت ,الاوكسجين, والنيتروجين. هذة المادة متعرضة بصورة دائمة للتغيرات الحرارية. وعند تعرضها للدرجات الحرارة العالية تتحول إلى مادة أشبة بالمائع. ولتفادي هذة الحالة الطبيعية لمادة التبليط ومعالجتها دعت الحاجة إلى تحسين خواص هذة المادة التي تحدث عند الدرجات الحرارة المنخفضة والتي تتحول إلى مادة أشبة بالمادة الصلبة وعند درجات الحرارة العالية تتحول إلى مادة اشبة بالمواد البلاستيكية ولذلك تم اضافة البوليمر إليها من اجل زيادة ثبوتية هذه المادة للتغيرات الحرارية .وتم اختيار خمس نسب لخلط البوليمر(اثيل فنيل اسيتيت) مع مادة التبليط وهي (5% ,7% ,9% ,11% ,و13%) ومن خلال الاختبارات العملية يمكن ملاحظة التحسن في الخواص الفيزيائية والميكانيكية باضافة البوليمر المشترك .وقد لوحظ انخفاض في نفاذية

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مادة التبليط وزيادة لزوجتها وكذلك زيادة في قيم اختبار مارشال . وتم مقارنة نتائج الخلطات المحسنة والخلطات غير محسنة وتم اختيار افضل نسبة خلط من المادة البولمرية ومادة التبليط . وتم دراسة النماذج المحسنة والغير محسنا.وتم حساب الخواص الميكانيكية والتي تتضمن اختبارات مارشال . استخدمت أربع معادلات لتحليل النتائج . من خلال المعادلات المطورة نستطيع حساب الخواص الميكانيكية لمزيج مادة التبليط دون الرجوع القياسات العملية.

Introduction

Bitumen, which has thermoplastic nature, water resistance and adhesion toward most other substances, is a primary engineering material. Asphalt binders are widely used in road paving and their viscoelastic properties are dependent on their chemical composition. The use of synthetic polymers to modify asphalt binder performance and extend the paving life. Important properties such as thermal susceptibility, aging at medium and intermediate temperatures and resistance to rutting and fatigue were improved. To minimize asphalt concrete pavements distress there are several ways, which could extent pavement service life[1]:

• Produce a new binder type with better physical, chemical and rheological properties.

• Improve the pavements and mix design.

• Improve the construction methods and maintenance techniques.

Polymers were used to modify bitumen in improving their characteristics with enhanced performances. Polymers used to modify the physical and rheological properties of bitumen are styrene butadiene styrene copolymer (SBS), styrene butadiene rubber (SBR), atactic polypropylene, ethylene-propylene copolymer and ethylenepropylene rubber, amorphous poly(〈 olefins), cellulose fibres, polyolefins, polyurethane and also epoxy resins

Waste and recycled materials may also be used as modifying agents in bituminous materials, for example, recycled polymer, scrap tyre rubber and wastes from petrochemical plants [2].

Bahia explained that fatigue cracking of flexible pavements is based on the horizontal tensile strain at the bottom of asphalt concrete layer[3]. A schematic representation of the Flexible pavement distresses fatigue cracking can be represented as in Figure 12

There are many researchers looking for the reasons to modify bituminous materials. Lewandowski mentioned that the main reasons to modify bituminous materials with different type of additives could be summarized as follows[4]:

• To obtain softer blends at low service temperatures and reduce cracking,

• To reach stiffer blends at high temperatures and reduce rutting,

• To increase the stability and the strength of mixtures,

• To improve fatigue resistance of blends,

• To reduce structural thickness of pavements.

Asphalt cements have diverse applications and are commonly used in flexible highway and airport pavements due to their adhesion properties and viscoelastic properties. Properly designed and manufactured, a typical pavement consisting of polymeric materials and asphalt performs quite satisfactorily in road construction.1 A high-performance pavement calls for resistance to high-temperature rutting and low temperature cracking.2 Increased traffic factors, such as heavier loads, higher volumes, and greater tire pressure, require better pavements. To improve the properties of asphalt materials, researchers have focused on the interaction of asphalt components and polymer additives [5]. Bahia studied the effect of polymer modification using scanning electron microscope images. The result showed that the modified asphalt concrete mixtures have better binder-aggregate adhesion, which led to increase in its toughness[6]. The main advantage of using polymer technology is to improve the adhesion properties between the binders and aggregate. Due to ever increasing traffic volume and loading, there is a continuing effort by pavement community to improve asphalt binder. Mechanical properties of asphalt binder can be adjusted to help extend the service life of asphalt pavement as well as minimize the potential pavement distress. The addition of polymer to asphalt binder can reduce potential rutting and fatigue cracking as well as increase cohesion and decrease temperature susceptibility. However, the addition of polymer to asphalt binder increase viscosity and stiffness thereby reduces the workability of asphalt mixture[7]. Hadidy Al, Qui Tan Yi studied focus on the use of thermoplastic copolymers namely, linear low density polyethylene (LLDPE), high density polyethylene (HDPE) and polypropylene (PP) as modifier for the base bitumen. Concentrations of all polymers were kept till 5% by weight of the bitumen. As most polymers when blended remains insoluble to certain extent in bitumen thus phase separation may occur which may be due to the formation of a multiphase system, a phase rich in asphaltenes not absorbed by the polymer (Bardesi A, et al. 1999) which enhances the viscosity by the formation of more complex internal structure [8].

Interaction between Bitumen and Polymer

The morphology of polymer modified bitumen is the result of the mutual effect of polymer and bitumen, consequently is influenced by bitumen composition, polymer nature and ratio [9]**.** Most polymers are insoluble to some degree, in the bitumen matrix, resulting eventually in gross separation of both phases. These phases may become a continuous phase or a dispersed one depending on polymer nature, concentration and its ability to swell with maltene molecules [10]**.** Bitumen phase is artificially enriched in asphaltenes by a physical distillation of the lighter species from the original bitumen because polymer is swelled by the maltenes. This is the case of many elastomers and thermoplastics such as EVA, SBS, PE etc. In general at low polymer content, the small polymer spheres swollen by bitumen compatible fractions are spread homogeneously in a continuous bitumen phase. By increasing polymer content, a continuous polymer phase may be obtained. The minimum percentage of polymer to ensure the formation of its continuous phase depends to a great extent on the base bitumen, the polymer itself and its ability to swell with maltene molecules **.** Polymer stabilization can be achieved by mechanical dispersion of the modifier, swollen by compatible components in the maltene fraction. It is well known that the polymer may dissolve and/or disperse into maltenic medium enhancing the mechanical properties of mixtures**.** SBS-modified asphalt increases in apparent volume due to swelling with malten incorporated from asphalt when SBS is mixed with asphalt. The butadiene phase of the polymer absorbs the lighter ends of the asphalt and swells as much as nine times its original volume. The butadiene phase is cross-linked by the styrene to form a continuous network throughout the asphalt when cooled and significantly changes the physical properties of the asphalt [11].As shown in Figure 11 [12].

Evaluation of mechanical properties

Marshall Stiffness (MS) is widely used to characterize the mechanical performance of asphalt concrete mixtures. It is considered a combined index that reflects both stability and plastic flow characteristic of the mixture. It is obtained from marshal stability testing using the following equation[13];

$$MS = \frac{S_i}{F_i b} \qquad \text{.......(1)}$$

Where

MS = marshal stiffness

S_i = Mixture`s stability at bitumen content (i)

F_i = Mixture`s flow at the same bitumen content (i)

.b = sample thickness

The indirect tensile test has been used extensively in structural design research for flexible Pavements since the 1960’s. A cylindrical specimen is loaded diametrically across the circular cross section. The indirect tensile strength test is performed to determine the tensile strength of the bituminous mixtures. Indirect tensile method is used to develop tensile stresses along the diametric axis of the test specimen. The horizontal tensile stress at the centre of the test specimen is calculated to determine the indirect tensile strength by doubling the peak load (P) and then dividing it by the diameter (d) of the sample and the thickness (t) of the sample using the following equation[14];

$$\sigma = \frac{2P_{max}}{\pi h d} \qquad \text{..........(2)}$$

Where:

σ :Indirect tensile strength (KN/cm^2), P_{max} : Maximum applied (KN),

H : Thickness of specimen (cm), and, d : Diameter of specimen (cm).

The unconfined compressive strength test is performed to determine the compressive properties of bitumen mixtures. The compressive strength of the mixtures can be obtained through applying a compression load on the circular face of a circular specimen.

The load is increased until failure occurs. The compressive strength can be calculated using the following expression[14];

$$\sigma_c = \frac{4P_{max}}{\pi D^2} \qquad \text{.......(3)}$$

Where σ_c is the unconfined compressive strength, P_{max} is the maximum applied compressive load and, D is the diameter of the specimen.

The optimum asphalt content of the various mixes is determined from Marshall Property curves. It is numerical average of the percentages of the asphalt content determined corresponding to maximum Marshall Test. It is determined according to the method described by the Asphalt Institute [15]

The bulk density is determined in accordance with method described by ASTM D2726 the weight of the specimen is measured in air and then in water at 25°C and then in condition of saturated surface dry condition. The bulk density (g/cm3) is the calculated as follows [16]:

$$G_{mb} = \frac{W_a}{W_{ssd} - W_w} \qquad \text{......(4)}$$

where:

G_{mb} = Bulk density of the compacted specimen.

W_a = Weight of specimen in air (gm).

W_{ssd} = Weight of saturated surface dry specimen (gm).

W_w = Weight of specimen in water (gm).

Experimental work

Materials

The materials used in current study are aggregate, asphalt, Portland cement as filler. The bitumen used in this study was of grade (60-70) Penetration. Some selected properties of this bitumen are shown in Tables 1. The thermoplastics copolymers ethylene vinyl acetate (EVA) was used for this study. EVA is the copolymer of ethylene and vinyl acetate. The molecule structure of EVA resins is represented as [-CH_2-CH_2-]$_m$-[CH_2-$CH(OCOCH_3)$-]$_n$ Incorporation of vinyl acetate in the ethylene polymerization Some selected properties of these polymers are shown in Table 2 process produces a copolymer with lower crystalline than conventional ethylene homo polymer. It has good clarity and gloss, barrier properties, low temperature toughness, stress crack resistance, hot melt adhesive and heat sealing properties and resistance to UV radiation.

Calculate for polymers:

The percentage of polymer and the weight of polymer can be calculate by using the following equation:

$$P = \frac{W_p}{W_p + W_a} \times 100 \qquad \text{.........(5)}$$

Where:

Wp is the weight of polymer to be added, Wa is the weight of asphalt and P is the percentage of polymer to be used .

Preparation of mixtures

The following blending sequence was used to modify bitumen materials with copolymer;

- Asphalt cement was heated in an oven at a temperature of at least 160 ^oC.
- The stainless steel beaker used for mixing was cleaned and kept in the oven.
- The required amount of asphalt was weighed into the beaker.

• Five blends were prepared with 5%,7%, 9%, and 11% EVA, by total weight of bitumen.
• The mixing temperature was controlled during mixing.

Physical properties

To study the effect of the polymer content on the base bitumen, penetration test (0.1 mm) at 25°C, and softening point (^oC) were examined according to ASTM D5 and ASTM D36

Mechanical properties

Marshall Specimens prepared with various Asphalt cement polymer content were tested to determine Marshall Properties. The procedure used for determining these properties are as The bulk density is determined in accordance with method described by ASTM D2726 [18] the weight of the specimen is measured in air and then in water at 25°C and then in condition of saturated surface dry condition. Marshall Stability and flow test is performed on each specimen in accordance with procedure described by ASTM. Resistance to the plastic flow of bituminous mixture using Marshall apparatus with Electronic recording system. The specimen is placed in water bath at 60 °C for (30-40) min. The Marshall stability is the maximum load in (KN), while the Marshall flow is the total movement or strain occurring in the specimen between no load and maximum load during the stability test.

Results and discussion

Figure 1 shows that, with increasing EVA content, the penetration point of the modified bitumen decreases, more than that of the unmodified bitumen. The maximum decrease was observed with 11% EVE content. This indicates that, the hardness and stiffness of bitumen have been increased when polymer modifiers were added. Figure (2) indicates that for the same asphalt content, the softening point for modified mixtures is higher than that of the unmodified mixtures. This means that adding polymer to bitumen has a considerable effect on improving its resistance to flow and deformation. The increase in softening point when polymer were added is an expected behavior due to the development of a continuous polymer network within the bitumen blend that tend to reduce the interpartical distance between the blend particle, which increases the softening point of the polymer-bitumen blend. Hence, thermoplastic polymer modified bitumen can perform better in hot climate areas as compared to unmodified bitumen [16].

The result of Marshall Stability tests for each of the mixtures is showing in figure 3 and 4. Figure 3 shows the Marshall stability for unmodified and different modified mixtures against percent of bitumen content. Figure 4 present the Marshall stability for unmodified and different modified mixtures against the percent of polymer content. It indicates that stability values for various mixtures are increasing with increase the percent of the bitumen content until a maximum value is reached 6% bitumen content after which stability tends to decrease. also the Marshall stability for different modified mixture are higher as compared with unmodified mixtures. The Marshall Stability of the modified mixtures increase with increasing the percent of the polymer content until a maximum value is reached 11% polymer content after which stability tends to decrease. Also the Marshall stability for different modified mixture is higher as compared with unmodified mixtures. This may be due to the increase in the viscosity of the modified bitumen mixtures, which lead to the formation of a thicker mixture film in asphalt. Wish lead to longer service life and more flexible pavement.

The curves in figure 5 and 6 represented the flow test for unmodified and different modified mixtures. Figure 5 present flow test values with respect to bitumen content. It is clear that flow values of unmodified and different modified bitumen mixture increase as the bitumen content increases. Figure 6 shows the flow test as a function to polymer content. Result of flow proved that bitumen mixtures, modified with ethylene vinyl acetate (EVA) have lower flow value compared to the base bitumen mixture. The reduction ranged from 13 to 15 when ethylene vinyl acetate (EVA) added to the bitumen mixture. This is due to the flexibility effect of EVA compared to unmodified bitumen mixture. The Marshall Stiffness value is presented in figure 7. It is indicate that the value of Marshall Stiffness is higher for the polymer modified mixtures than its counterpart for unmodified mixtures. It is also indicate that the Marshall Stiffness increases with increasing the copolymer content up to 11% copolymer content after which Marshall stiffness tend to decrease. The Marshall stiffness of a mixture depends on the internal friction and cohesion. Cohesion results from bending ability of bitumen [17]. High Marshall Stiffness of the modified bitumen mixtures are caused by the high workability of the mixture with polymer. The indirect tensile test was developed to determine the tensile properties of bitumen mixture through application of compression load along the samples.

Figure (8) shows the unite weight values for various mixtures as a function of bitumen content .In this figure unite weight curves of both unmodified and modified mixtures' show the same trend that is expected from hot mixes prepared with various asphalt contents where the unite weight increases with increasing asphalt content until a maximum value is reached after which the bulk density tends to decrease. Also, Figure (8) shows that for the same asphalt content, the unit weight for control mixes is higher than that of various modified mixes. These reductions in values of unit weight for modified mixes results from the low specific gravity of the polymer content.

The optimum asphalt content for unmodified mixtures is 6% while for the modified mixes is 5.7, 5.58, 5.46, 5.34, and 5.22 for (5%, 7%, 9%, 11%, and 13%) respectively. Therefore, it can be conclusion that the optimum asphalt content for modified mixtures is (6).

The curves in figure 9 represent the indirect tensile strength values for all samples mixtures as a function of polymer content and bitumen content. This figure shows that for modified mixes, The indirect tensile strength increases with an increasing polymer content until 11 percent reached after that The indirect tensile strength decreases.. It is evident from that figure that ethylene vinyl acetate (EVA) modified mixtures had the highest indirect tensile strength, while the unmodified mixtures had lowest indirect tensile strength. This gives the impression that modification has enhanced the tensile and toughness properties of bitumen mixtures. The EVA modified mixture has the highest indirect tensile strength as a compared of unmodified bitumen. Hence, it can be concluded that the EVA modifier has a potential to increase the mixtures toughness and resistance to tensile stresses. The unconfined compressive strength test was performed to determine the compressive properties of the studies mixtures. The unconfined compressive strength for various mixtures is calculated based on equation 3. Figure 10 shows the effect of Polymer content percent on unconfined compressive strength. As seen in figure 9, the unconfined compressive strength in total mix increase with increasing Polymer content. This reflects the enhancement in the mixture resistance to compressive stresses due to adding polymer modifiers. In view of the above result, it is evident that the mixtures mechanical properties have considerably increased when polymers added. This is indicative of an improvement in the interfacial strength between the binder and the other component. This can be related to the ability of polymers increase the adhesive bond between bitumen other component. The modified mixtures is due to the fact that the ethylene vinyl acetate (EVA) is a polymer that approaches elastomeric materials in softness and flexibility, yet can be processed like other thermoplastics. So it can improve both the mixture elasticity and stiffness.

The analysis of empirical correlation

The experimental results of this study are used to develop empirical correlation. The statistical program was used to analytical the experimental results to obtain best correlation for this work. The method of developing the empirical correlations is introducing equations of different forms in this program. The calculated values of the dependent variables are compared with the actual experimental values and the method is repeated until excellent agreement is obtained with the maximum number of iteration. The dependent and independent variables were used as input data in such a way that the developed models could be used for the bitumen mixture with polymer content to find the change in mechanical properties with adding the polymer to the bitumen mixture, the independent variables, which affect the mechanical properties of bitumen mixtures, are weight percent of polymer content and bitumen content. Equations (6), (7) and (8) represent the developed models for the Marshall Stiffness, indirect tensile strength, unconfined compressive strength with weight percent of polymer and bitumen content respectively. The predicted and experimented values for equation 6, 7, and 8 are showing in figures 13, 14, and 15, respectively. The practical use of such equations, given the value of the mechanical properties with the polymer and bitumen content without needs any experimental data points itself. Also from equation 6 and 7 can be calculated the Marshall stability and flow test. Equation 9 represents the stability (KN) as a function of flow (F), sample thickness (b), polymer content, and bitumen content. Table 3 represented the parameters of equations6, 7, 8, and 9.

$$MS=A_1+A_2\ BC+A_3\ PC+A_4BC^{-2}+A_5PC^4+A_6\ (PC/BC)^{0.3}$$
R=0.98637 ……(6)

$$ITS=A_1+A_2\ BC+A_3\ PC+A_4BC^{-2}+A_5PC^4+A_6\ (PC/BC)^{0.3}$$
R=0.98862 …..(7)

$$UNC=A_1+A_2\ BC+A_3\ PC+A_4BC^{-2}+A_5PC^4+A_6\ (PC/BC)^{0.3}$$
R=0.99616 …..(8)

$$S_i = F_i b\left(A_1 + A_2 BC + A_3 PC + A_4 BC^{-2} + A_5 PC^4 + A_6\left(\frac{PC}{BC}\right)^{0.3}\right) \quad ……(9)$$

Where

MS is the Marshall stiffness (KN/cm^2).

ITS is the indirect tensile strength (KN/cm^2).

UNC is the Unconfined Compressive strength (KN/cm^2).

S_i is the stability (KN).

PC is the polymer content.

BC is the bitumen content.

A_1, A_2, A_3, A_4, A_5, and A_6 are the parameters for equations 6, 7, 8, and 9.

R is the correlation factor.

Advantages of Using Asphalt Additives

1. Asphalt additives improve durability, crack resistance, asphalt binder elasticity as well as increase the pavement life.
2. Adding rubber to asphalt increases its flexibility and reduces cracking and it gives some benefits for both the economy and the environment more than commercial polymer.
3. Blending bitumen with additives expands the useful temperature range of the modified bitumen and increases the temperature susceptibility.
4. Using EVA improve the rheological properties and fatigue resistance for modified bitumen binder and mixtures.

Conclusions

In this study can be concluded the following

1-The polymer modification has enhanced physical properties of bitumen mixtures.

2- The penetration of the bitumen decreases with increasing the copolymer content

3- The hardness and stiffness of bitumen have been increased when polymer modifiers were added.

4- Adding polymer to bitumen has a considerable effect on improving its resistance to flow and deformation.

5- The Marshall stability for different modified mixture is higher as compared with unmodified mixtures. Also, The Marshall Stability of the modified mixtures increase with increasing the percent of the polymer content until a maximum value is reached 11% polymer content after which stability tends to decrease.

6-Adding EVA leads to decrease flow value.

7- The unit weight for control mixes is higher than that of various modified mixes.

8-The optimum asphalt content for an unmodified mixture is 6

9- The indirect tensile strength increases with an increasing polymer content until 11 percent reached after that the indirect tensile strength decreases.

10- The EVA modifier has a potential to increase the mixtures toughness and resistance to tensile stresses.

11- The unconfined compressive strength in total mixtures increase with increasing Polymer content.

12- The modified mixtures is due to the fact that the EVA is a polymer that approaches elastomeric materials in softness and flexibility.

13- Develop empirical correlation using statistical program.

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Table 1 Properties of 60/70 penetration grade bitumen used in the study.

PROPERTY	ASTM	UNIT	VALUE
Penetration at 25 0C, 100 g, 5 sec	D 5	x 0.1 mm	60-70
Softening Point (ring and ball method)	D 36	0C	45-55
Solubility	D 2042	wt %	99

Table 2 Properties of copolymer EVA

PROPERTY	UNIT	VALUE
Melting point	°C	61 - 67
Density @ 23°C	kg/m3	945
Vinyl Acetate content	%	35
Young modulus	MPA	3000
Water absorption	%	0.09

Table 3 Parameters of equations 6, 7, 8, and 9.

Equations	A_1	A_2	A_3	A_4	A_5	A_6
Equation 6 and 7	46.25852	-4.96504	0.518684	-454.55	-9.5E-05	-1.80262
Equation7	5.359817	-0.56051	0.078922	-50.2061	-1.6E-05	0.04233
Equation 8	1.620363	-0.16619	0.045849	-13.7041	-8.6E-06	-0.04573

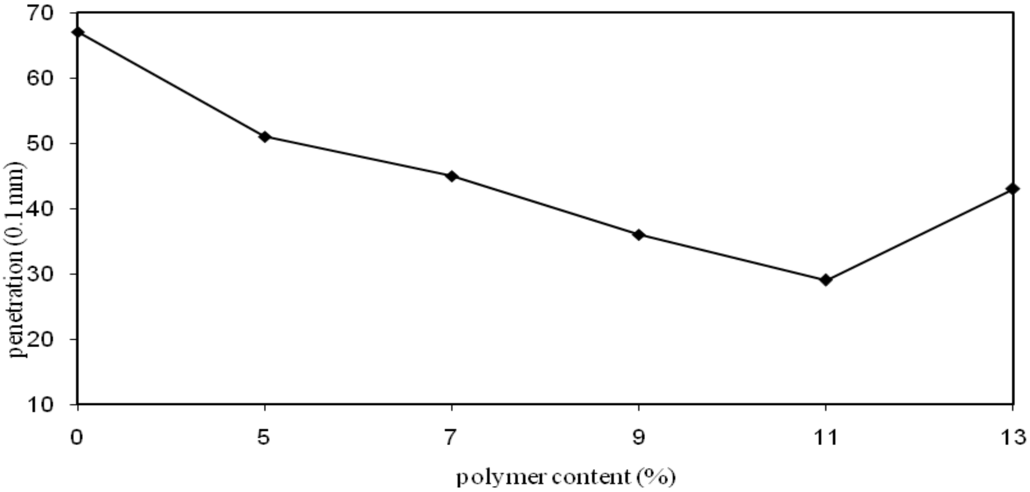


Figure (1) the effect of the percent of copolymer content on the penetration for modified bitumen mixture.

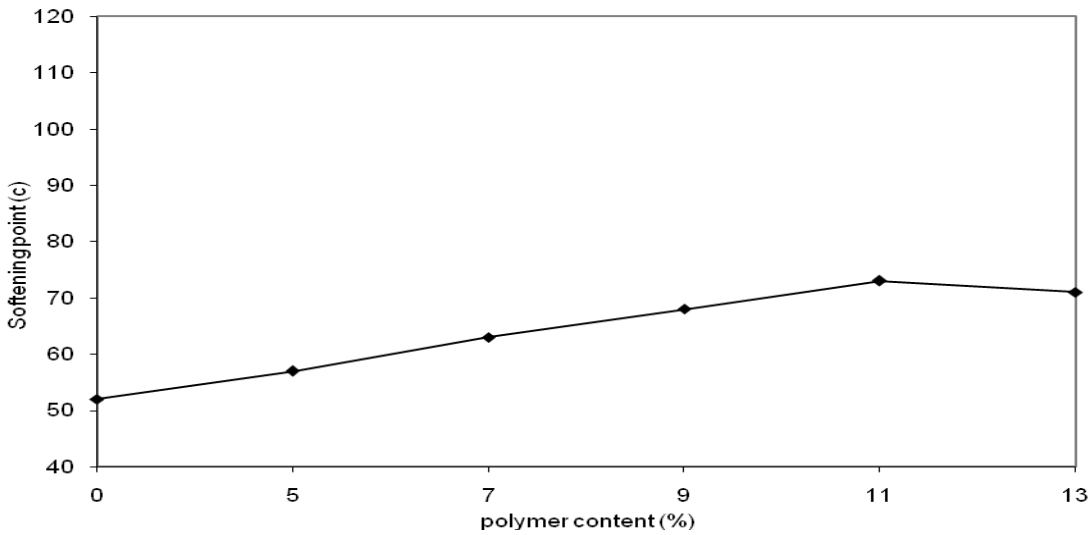
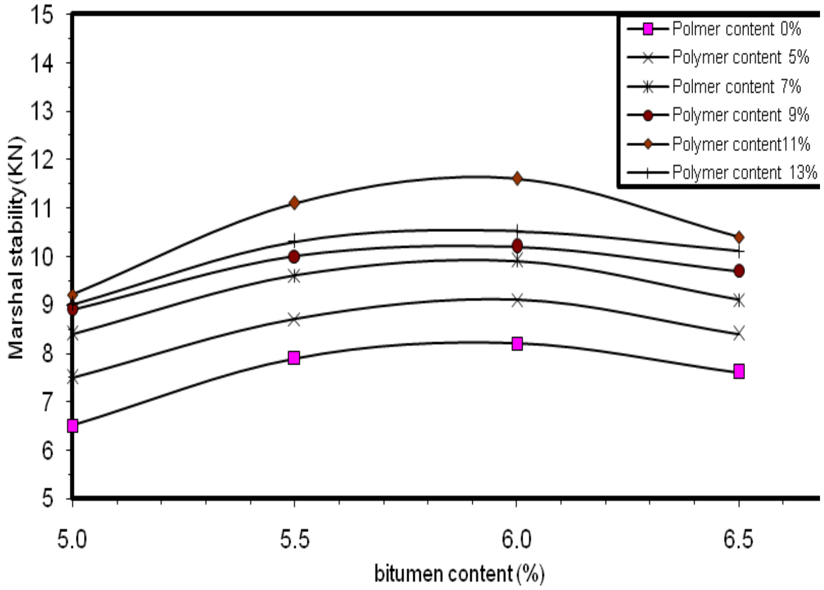
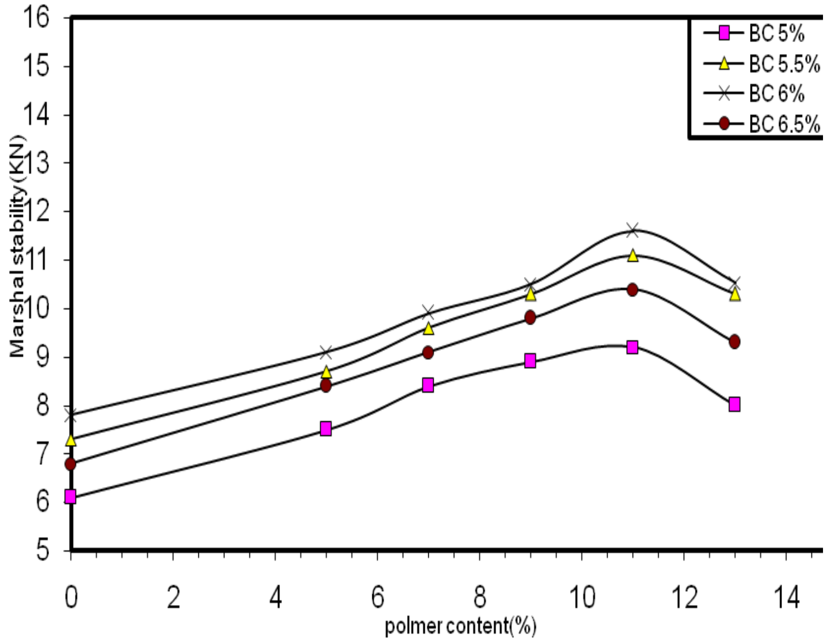


Figure (2) the effect of the percent of copolymer content on the softening point for modified bitumen mixture.



Figure(3)the effect of the percent of bitumen content on the Marshall stability for modified and unmodified bitumen mixture.



Figure(4)the effect of the percent of polymer content on the Marshall stability for modified and unmodified bitumen mixture.

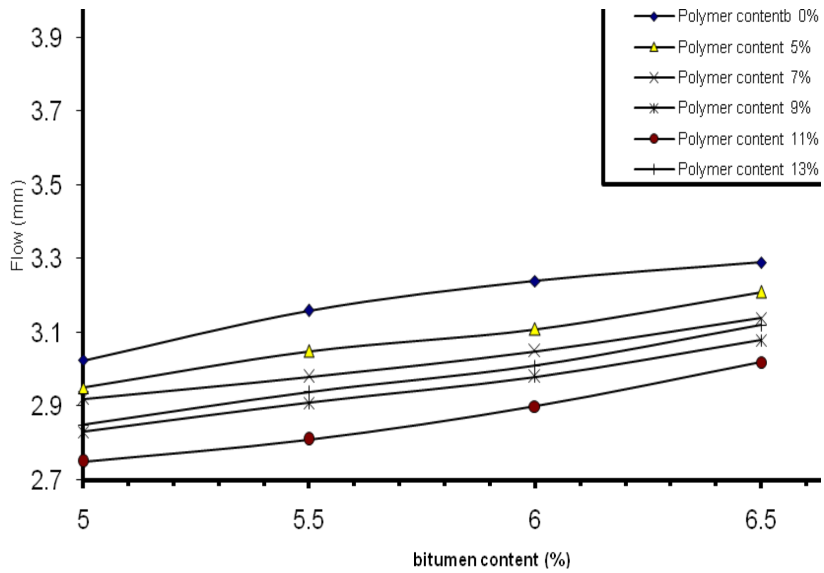
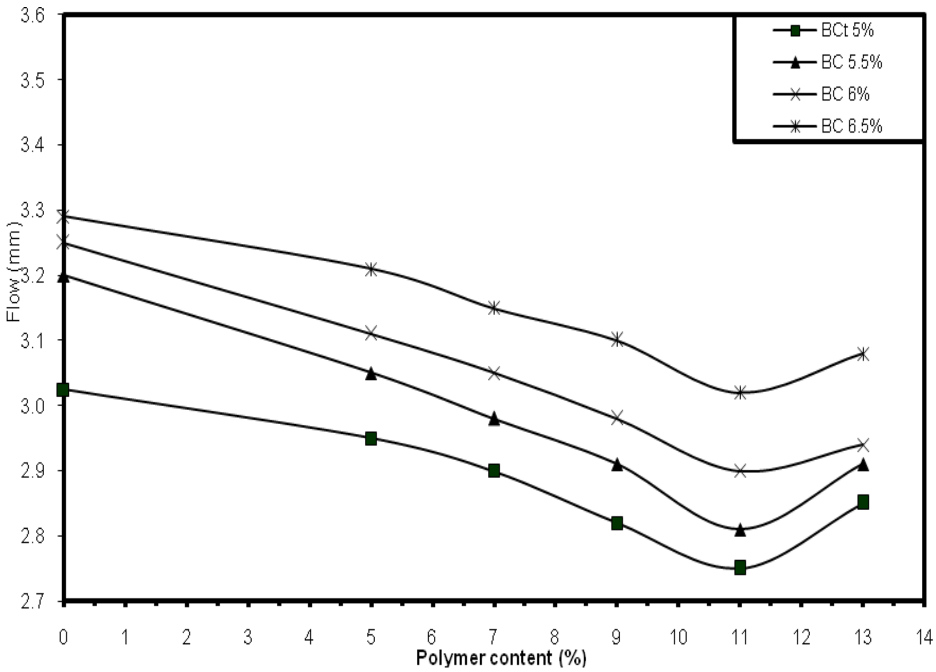


Figure (5)the effect of the percent of bitumen content on the Marshall flow for modified and unmodified bitumen mixture.



Figure(6)the effect of the percent of copolymer content on the Marshall flow for modified bitumen mixture.

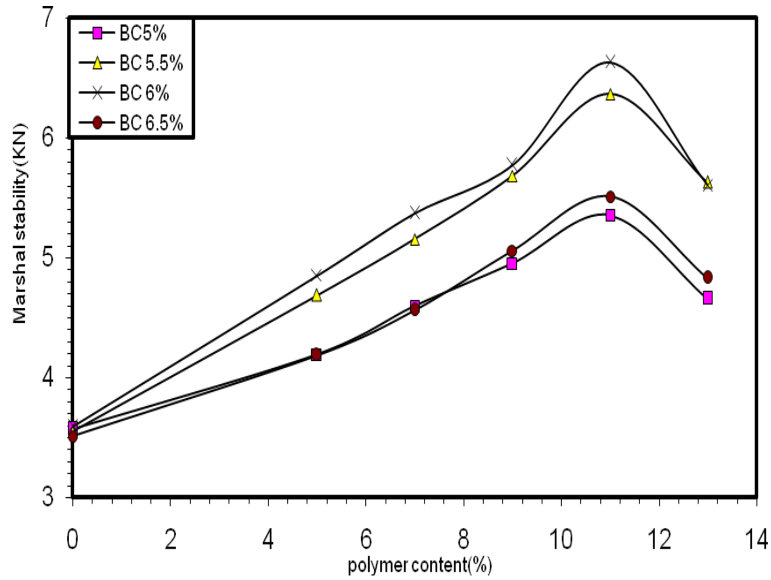
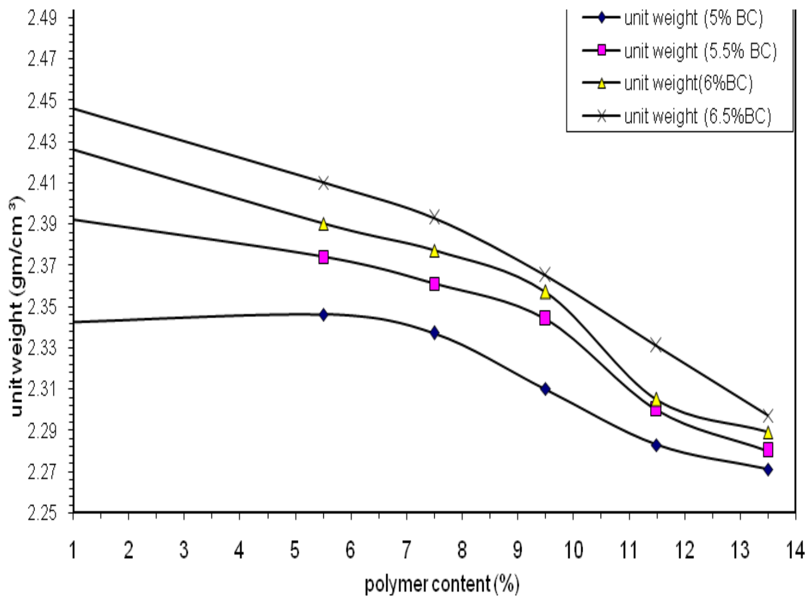


Figure (7) the effect of the percent of copolymer content on the Marshall stiffness for modified bitumen mixture.



Figure(8) the effect of the percent of copolymer content on the unit weight for modified and unmodified bitumen mixture.

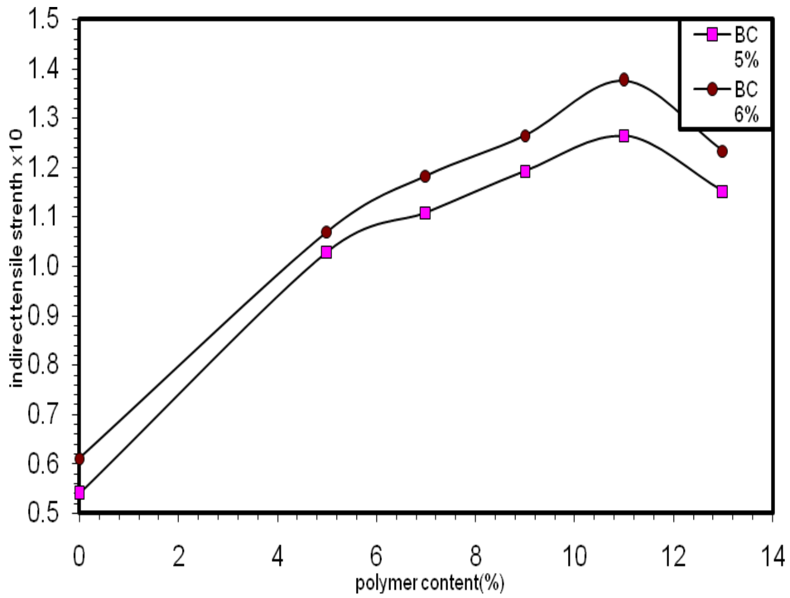


Figure (9) the effect of the percent of copolymer content on the indirect tensile strength for modified bitumen mixture.

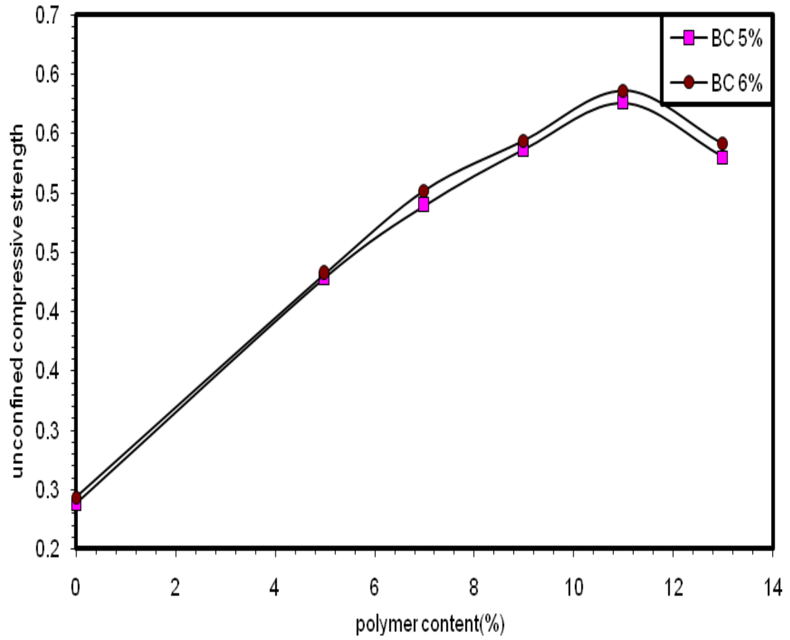


Figure (10) the effect of the percent of copolymer content on the unconfined compressive strength for modified bitumen mixture.

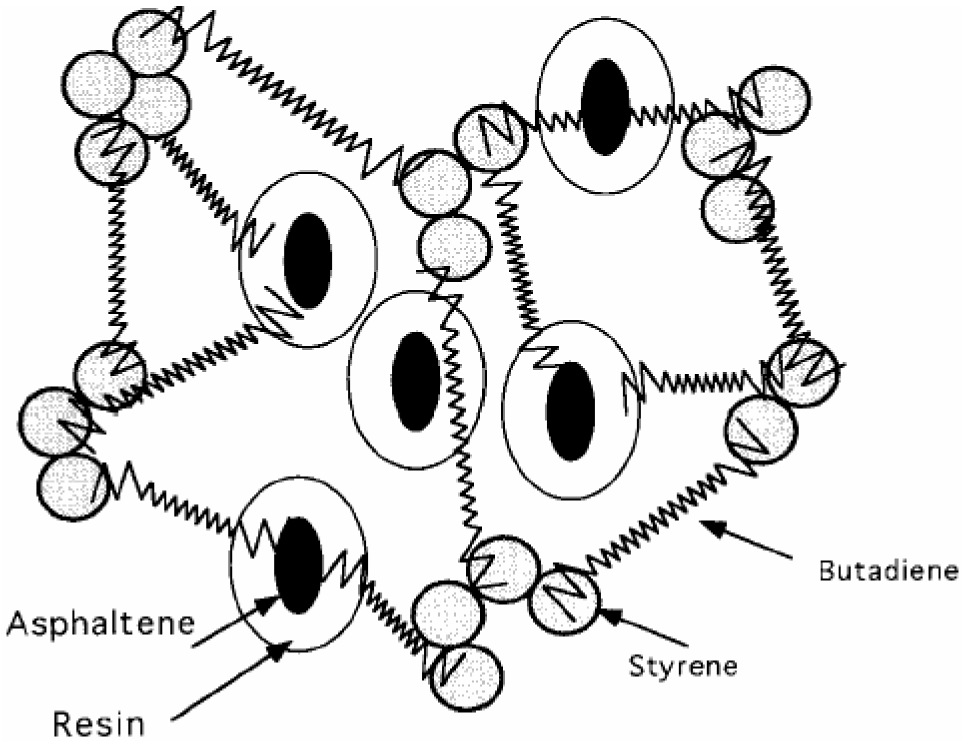


Figure (11) The SBS interacts with the asphaltene micelles forming a three-dimensional network if the SBS content is sufficiently high [12].

Figure (12) Flexible pavement distresses fatigue cracking (Bahia)

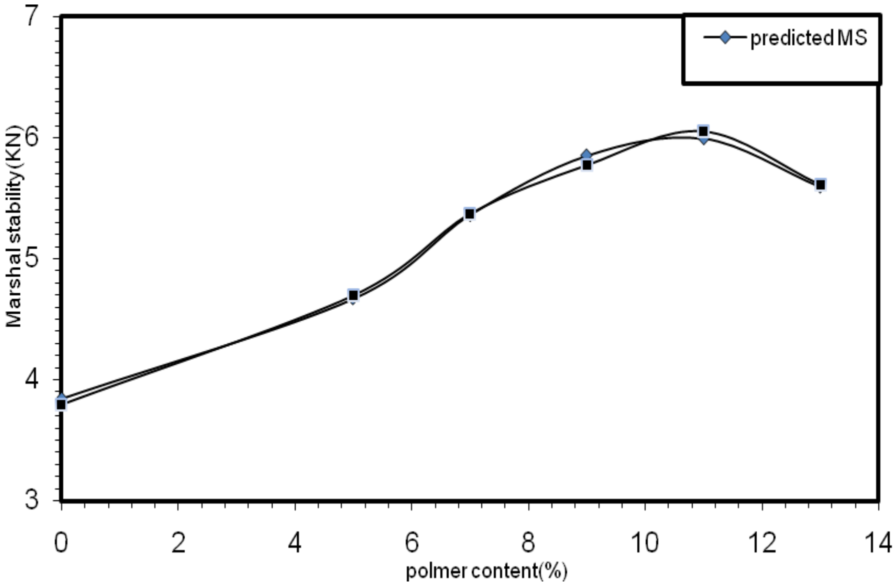


Figure (13) polymer content verse predicted and experimented MS

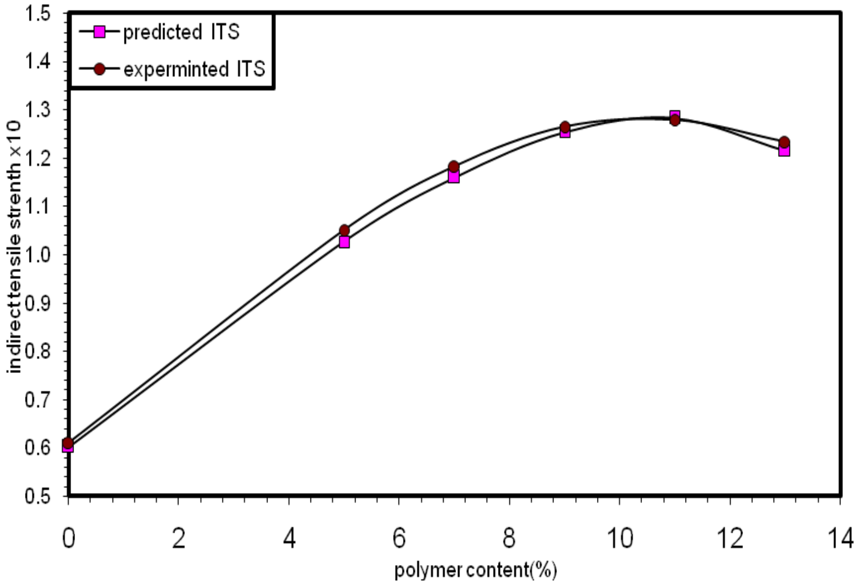


Figure (14) polymer content verse predicted and experimented ITS

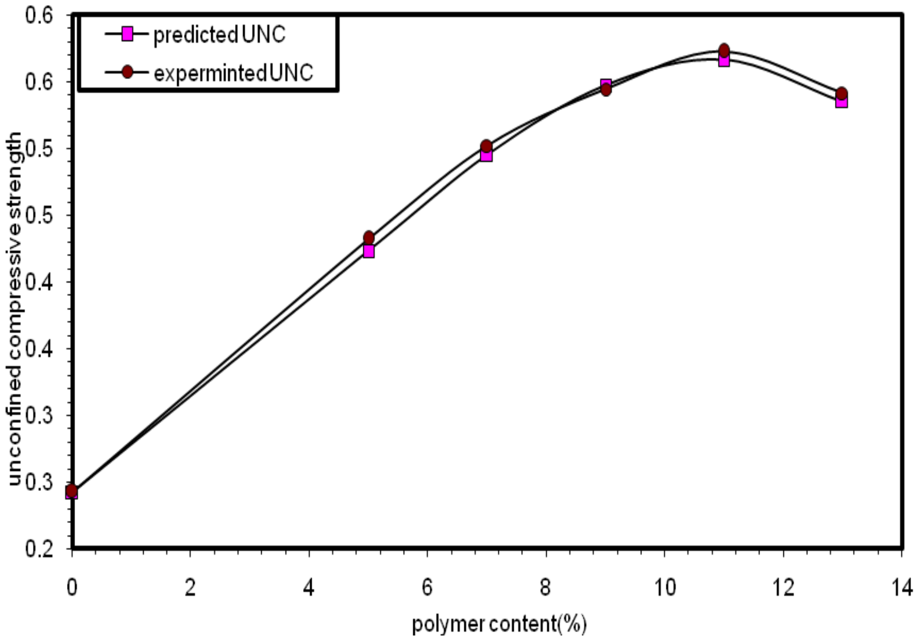


Figure (15) polymer content verse predicted and experimented UNS