Investigation on Tensile Strength Ratio (TSR) Specimen to Predict Moisture Sensitivity of Asphalt Pavements Mixture and Using Polymer to Reduce Moisture Damage

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Abstract

Moisture damage of asphalt concrete is defined as losing the strength and Permanence caused by the active presence of moisture.The most common technique to reduce moisture damage is using modifiers with the asphalt binder or the aggregate.The goal of this study was to explore the effect of various modifiers of polymer on the moisture susceptibility mixture of asphaltic concrete pavement. Modifiers included in this research selected two kinds of polymers Crumb Rubber No 50 (CR No 50) and Methyl Methacrylates (MMA)which are available in the local markets in Iraq and have been used in three percentages for each type. These percentages are (5, 10 and 15)% for (CR No 50) and (2.5, 5 and 7.5)% for (MMA).Each type of these polymers is blended with asphalt by wet process at constant blending times for a suitable range of temperatures. The experimental works showed that all polymers modified mixtures have indirect tensile strength higher than control asphalt mixtures, its about (2-15) %, dependent on different type of polymer and polymer concentration under predicted suitable blending time.Test results of indirect tensile strength indicated betterment in modifying the proprieties of mixture, the increased resistance mixture of asphalt concrete pavement versus moisture damage, and reduced the effect of water on asphalt concrete properties. The final result is the addition of (10% CR No 50) and (5% MMA) to asphalt mixtures showed an improved mixture of asphalt concrete properties and produced strong mixtures for road construction.One model is predicted for tensile strength ratio [TSR]to estimate the effects of polymer modification on moisture susceptibility mixture of asphalt concrete.

Key Words:- Asphalt, polymer, Indirect Tensile Strength, Moisture Damage.

الخلاصة

يعرف الضرر الناتج بسبب الرطوبة في الخرسانة الاسفلتية بفقدان القوة والمتانه بسبب وجود محتوى رطوبي فعال، الاسلوب الاكثر شيوعا للتخفيف والحد من ضرر الرطوبة هو استخدام المعدلات مع الاسفلت او مع الركام. ان الهدف من هذه الدراسة هو دراسة تأثير المعدلات المختلفة من اللدائن (البوليمرات) على تاثروحساسية خلطة الخرسانة الاسفلتية بالرطوبة، وقد تم اختيار المعدلات الواردة في هذه الدراسة هي نوعين من اللدائن (البوليمرات) المطاط الناتج عن سحق الإطارات المستعملة (CR) والاكرلات (MMA) المتوفرين في الأسواق المحلية وتم استخدامها بثلاثة نسب مختلفة لكل نوع هي (5, 10, 15)% من ال (CR)و بنسب (2.5, 5, 7.5)% من ال (MMA)، كل نوع من هذه البوليمرات خلط مع الاسفلت بواسطة عملية الخلط الرطبة وبأوقات ثابة محددة سابقا وبدرجات حرارة معينة. واظهرت التجارب المختبرية ان جميع الخلطات المعدلة بالبوليمر تمتلك مقاومة شد غير مباشر اعلى من الخلطات الاسفلتية الاعتيادية الغير معدلة بحوالي من %(2–15) تعتمد على نوع البوليمر وتركيز البوليمر تحت زمن خلط متوقع ومناسب، ان نتائج اختبار مقاومة الشد غير المباشر تبين تحسن خصائص المزيج المعدل وبالتالي زيادة مقاومة الخرسانة الاسفلتية للأضرار الناتجة بسبب الرطوبة وتقليل تأثير الماء على خواص الخرسانة الاسفلتية، وكنتيجة نهائية، إضافة 10٪ (CR) رقم 50 و 5% (MMA) لمخاليط الأسفلت أظهرت تحسين خصائص خلطات الخرسانة الإسفلتية وإنتاج خليط يمتلك ديمومة جيدة عند انشاء الطرق.موديل احصائي واحد متوقع للنسبة المؤية لمقاومة الشد (TSR) لتخمين تأثير التعديل بالبوليمر عل تحسس تأثير الرطوبة على خلطة الخرسانة الاسفلتية.

الكلمات المفتاحية :- الاسفلت، البوليمر، مقاومة شد غير مباشر، ضرر الرطوبة.

1- Introduction

The Moisture damage is one of the primary kinds of distress in mixture of asphalt concrete pavement, Iraq roads, severe problems of moisture damage in addition to other problems. It is caused generally by two major reasons, the first problem due to bad construction and the second due to poor design of the asphalt mixture, these reduce the resistance and durability when it is exposed to water directly. Commonly known as striping, this damage accelerates structural degradation of the mixtures in conjunction with cracking and plastic deformation (Kim, 2006). Water is majorly influencing the mechanical properties and physical properties of asphalt paving mixtures in our country. In point of fact, the moisture damage in mixture of asphalt concrete pavements is a global worry. Moisture damage in mixture of asphalt is definite as the loss of resistance, durability and stiffness due to the existence of moisture and leading to adhesive defeat (Farooqi *et.al.,* 2015). Qing (2005: 1) argues that " [M]oisture damage often directly disrupts the integrity of the mix, so it can reduce pavement performance life by accelerating all distress modes of interest in pavement design, including fatigue cracking, permanent deformation (rutting) and thermal cracking occurring in the asphalt concrete." . The result of losing strength or stiffness is reversible when water is removed from the mix, when the asphalt concrete pavement is loaded through weak condition (Santucci, 2002). To reduce the retrogradation and that way to increase the long term strength and durability of asphalt concrete pavement, and therefore to improve the resisting of asphalt concrete to moisture damage, many methods were obtained, all of which depend on the modified asphalt concrete properties.

2- Objectives

The objectives of this research are explained in the following points:

1. To determine the effect modifiers of polymer on the moisture susceptibility of asphalt concrete.
2. To determine which modified binders provide better properties and the amount of modifiers that should be used for getting a higher tensile strength ratio (TSR) and which is better in the moisture damage resistance.
3. A prediction statistical model for tensile strength ratio (TSR) in asphalt concrete mixture by considering the local material properties.

3- Materials for Asphalt Mixtures

3-1 Aggregates

The aggregates used in this research (fine aggregate and coarse aggregate) were originally obtained from AL-Najaf quarries. The aggregates were sieved and recombined to meet the requirements of wearing course aggregate gradation (Type IIIA) agreeing to General Specification for Roads and Bridges (SCRB) requirement *(SCRB, 2004: Section R/9)*. Physical's properties of aggregates are shown in table1, while table2 shows the aggregates gradation.

3-2 Mineral of filler

One kind of mineral fillers are using; normal portland cement brought from northern of Iraq (Tasluja). The Physical properties of the mineral filler are offered in table3.

3-3 Asphalt

Just one kind of asphalt is used with performance grade (PG70-16) and penetration grade (40-50) gotten from AL-Daurah refinery. Physical properties of this type of asphalt are presented in table4.

3-4 Polymers

3-4-1 Crumb Rubber (CR)

Crumb rubber, it is brought from Al-Najaf tire factory. It is black particles and recycled from the used tires (specific gravity is 1.13) with various practical sizes. One size is obtained from sieving analysis at sieves (No 50 (0.3mm), different percentages of polymer (CR) are investigated with ((5%), (10%) and (15%)) by weight of asphalt cement.

3-4-2 Methyl Methacrylates (MMA)

Methyl Methacrylates were brought from medical shops, which is a rose-colored powder, density 0.945 g/cm³ and this type was used for teeth medication. Methyl methacrylate is a transparent thermoplastic material of moderate mechanical strength and outstanding outdoor weather resistance. Acrylates and Methacrylates are polymerized from the polyethylene (PE) backbone (Baker, 2001). Different percentages of polymer (MMA) are investigated with ((2.5%), (5%) and (7.5%)) by the weight of asphalt.

4-Laboratory Specimen Preparation and Test Method

4-1 Specimen Preparation

Duplicate test specimens of controlled air void contents were prepared in the laboratory conditions. For the indirect tensile strength test (ITS), Dimensions of specimens (100mm) in diameter x (60mm) in height and it is prepared by using the compaction apparatus.

4-2 Conditioning of moisture

Conditioning of moisture is a significant step in the estimation of moisture damage of hot mix asphalt mixtures. Most study activities that evaluate the moisture harm of hot mix asphalt mixtures are base on comparing the several properties of the mix before moisture cases of conditioning and after it. Properties before the use of moisture conditioning are perfect referred to as (dry case) or (unconditioned case) whereas the properties afterward moisture cases of conditioning are perfect mentioned to as (wet case) or (conditioned case).

4-3 Type Binder of Mixing.

The type binder of mixing used in this research is (wet adding method), wherein the polymer is added to the asphalt cement before inserting it in the processing of mixture asphalt concrete. Polymer is added to asphalt cement at a blending with speed about (2620 rpm). The optimum blending time between asphalt cement and polymer that needed to produce a good performance for (CR) modify of asphalt is found to be less than that of (MMA) modify of asphalt, (60-80) minutes at a temperature (190°C) and (100-120) minutes at a temperature (180°C) respectively, *(*AL-Bana'a, 2009).

4-4 Marshall Test

This test is carried out according to the (ASTM (D-6927)) to find the optimum asphalt content for compact asphalt concrete specimens. Four dissimilar percentages asphalt contents ((4.2%), (4.8%), (5.4%) and (6%)) are used to wearing course type (A). The typical optimum asphalt contented (O.A.C) of the various mixes is determined from the following Marshall, (stability, flow and 4% of air voids). The optimum asphalt is (4.8) %.

4-5 Tensile Strength Ratio (TSR)

The tensile strength ratio (TSR) is conducted in agreement with *(AASHTO – (T283)),* in this test method we measure the resistance of compressed mixtures of asphalt concrete to moisture damage. In this test, the sample is loaded at a stable deformation rate of (2inches) per (1 minute) or ((50mm) per (1minute) of vertical ram movement of the sample until failure *(AASHTO, 2005)*. Two cases are tested in this study, first one symbolizes the control models and the modified models (unconditioned case) which are tested at (25°C). The second is (the conditioned case), which is inundated in water at (60°C) for (24 hours), and are tested at (25°C). For both kinds of cases, indirect tensile strength is calculated according equation1, and tensile strength ratios [TSR] of indirect tensile strength (ITS) for condition models case to the (ITS) of unconditioned model cases were calculated agreeing to equation2, and moisture harm resistance index was used for mixture of asphalt. Higher tensile strength ratio [TSR] improves the resistance of moisture damage. *AASHTO (2004-2005: T283-7 and T283-8)* argues that "[c] alculates the tensile strength and tensile strength ratio as follows:

$$ITS = \frac{2 \times P}{\pi \times t \times D} \quad \text{------------------} (1)$$

Where:-
ITS: Indirect Tensile Strength (Mpa).
P: Peak Load (N).
t: Thickness of specimen (mm).
D: Diameter of specimen (mm).

$$\text{Tensile strength ratio (TSR)} = \frac{ITS_2}{ITS_1} \quad \text{------------------} (2)$$

Where:-
ITS_1: the indirect tensile strength of the dry subset (unconditioned) (Mpa).

ITS_2: the indirect tensile strength of the conditioned subset (Mpa)."

5- Laboratory Test Results and Discussion

5-1 Results of Tensile Strength Ratio (TSR)

The results of this test are shown in table5, table6 and table7, The tensile strength ratio dependent on the result of indirect tensile strength in two cases (conditions and unconditioned) are calculated, indirect tensile strength of modified mixtures varies according to the type of polymer and concentration of polymer. Generally, Figures 1 and 2 are expressed to indicate the effects of polymers on the indirect tensile strength of modified mixtures. The indirect tensile strength of unmodified (control) mixtures 2.177 Mpa and 1.763 Mpa for (unconditioned) and conditioned cases, respectively, are less than that of the modified mixtures with polymers regardless of the concentration. The highest ITS is recorded for asphalt mixture with modified content (10% CR is 2.415 Mpa and 2.108 Mpa for (unconditioned) and (conditioned) cases, respectively) and (5% MMA is 2.501 Mpa and 2.216 Mpa for (unconditioned) and (conditioned) case, respectively). Asphaltic mixtures modified with (5%MMA) have higher indirect tensile strength than those modified by (10 % CR) are shown in Figures 1 and 2. The results of tensile strength ratio (TSR) presented in Figure3 shown the value of TSR for unmodified mixture equal to (80.98%) which is within the required limit (most agencies use a minimum value of TSR = 80% in the moisture sensitivity test for HMA mixtures), for asphalt mixture with modified Crumb Rubber (CR), TSR rises with the increase of (CR) content until it arrives to optimum content (10%) with TSR equal to (87.28%) then it decreases, and for asphalt mixture with modified Methyl Methacrylates (MMA) TSR rise with the increase of (MMA) content until it arrives to the optimum content (5%) with TSR equal to (88.60%) then it decreases. The conclusion for the two indicate (CR and MMA), that the moisture damage resistance rises with the increasing of TSR index.

5-2 Effect of Modified Mixture on Air Voids

The effects of (CR) and (MMA) polymers on the ratio of air voids are presented in table1 and tabl2. It's shown in the tables that the ratio of air voids reduced with increased (CR) and (MMA) content, the optimum content is10% of CR and 5% of MMA, respectively, and increased for (CR) and (MMA) percentages

(15%) and (7.5), respectively. As the beneficial application of 10% CR and 5% MMA to the asphalt cement to get better properties of a mixture asphalt concert by decreasing the ratio of air voids, its effects on the durability of mixtures against the moisture damage caused by environmental effects.

6- Statistical Model for Analysis

6-1 Model and Variables

The model that is derived from the results of this study of the effect polymers on the performance on the mixtures of asphalt concrete by a computer software *(STATISTICA) version (V5.5A)* as expressed in Table 8. In this Table Tensile strength ratio is determined as related to polymer type and, polymer percentages and other factors, where the selected variables and related factors for model as follows:

The dependent variables: TSR.

The independent variables: PT, PP, AV, ITS_1, ITS_2.

Where:-

TSR: Tensile strength ratio (%).

PT: Polymer type (1=control, 2= Crumb Rubber, 3= Methyl Methacrylates).

PP: Percent by weight of polymer from asphalt cement (%).

AV: Percent air voids (%).

ITS_1: Indirect tensile strength (unconditioned) (Mpa).

ITS_2: Indirect tensile strength (conditioned) (Mpa).

6-2 Approaches of Model Adequacy Assessment

In general, two methods are used to estimate the adequacy of the suggested regression model, the first one is based on the examining of the exact measures aimed at computing how good the suggested regression model obtained fits data. Usually measure presented is the coefficient (R^2), and the second method is based on the analysis graphically, it's called (diagnostic plots), which includs the Regression adopted models which are nonlinear and having a higher coefficient of determination R^2, (Devore, 2000). All models are rationally based on the diagnostic plots in which the distributions of residuals are distributed normally as shown in Figure 4.

7- Conclusions

Based on the research findings:

1. The(CR No 50) modified asphalt mixtures with 10% polymer content and the (MMA) modified asphalt mixtures with 5% polymer content have the best indirect tensile resistance. These percentages represented the optimum percent of concentration for polymers.
2. The modified specimens have the highest value of the indirect tensile strength values when compared with the control specimens. It's about (2-15) % times higher than the control asphalt mixes.
3. The addition of (CR No50) and (MMA) had given a good tensile strength for conditioned and unconditioned cases; so TSR values rise from (80.98%) to (87.28 %) for CR No50 and (88.60%) for MMA which improves moisture damage resistance.
4. The model is predicted to estimate the effect of polymer on the tensile strength ratio index [TSR] in asphalt concrete:

$TSR \propto PT$ & PP.

$TSR \propto AV$.

Where:-

TSR: Tensile strength ratio.

PT: Polymer type.
PP: Percent by weight of polymer from asphalt cement.
AV: Percent air voids.

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(MMA) Polymer on the Tensile strength ratio (TSR).
FIGURE 4: Diagnostic Plots of Model (TSR).

Table 1: Physical Properties of Aggregate.

Property	ASTM Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 C-128	2.51	2.67
Apparent Specific Gravity	C-127 C-128	2.65	2.71
% Water Absorption	C-127 C-128	0.88	0.84
% Wear (Los Angeles)	C-131	26 Max 35%	-----
Angularity	D 5821	94% Min 90%	-----

Table 2: Asphalt Mixture Grading for Surface (Wearing) Course (Type IIIA).

Sieve size		(% Passing by Weight of Total Aggregate + Filler)	Specification limits for Wearing Coarse (SCRB),Type IIIA
Standard Sieves (mm)	English Sieves (in)		
19	3/4''	100	100
12.5	1/2''	95	90-100
9.5	3/8''	83	76-90
4.75	No.4	59	44-74
2.36	No.8	43	28-58
300 um	No.50	13	5-21
75 um	No.200	7	4-10
Asphalt Cement (% weight of total mix)		4,8	4 - 6

Table 3: Physical properties of the used filler.

Property	Cement Filler	SCRB Specification(R9/2003)
Specific Gravity	3.13	- - - - - - -
Percent Passing Sieve No. 200Gravity	95	70 - 100

Table 4: Physical Properties of Asphalt Cement.

Tests	Units	Penetration Grade (40-50)	S.C.R.B Specification
Penetration (25 ^{0}C), 100 gm, 5sec) ASTM D-5	1/10 mm	46	(40-50)
Kinematic Viscosity at 135 ^{0}C ASTM-2170	cst	385	-----
Ductility (25 ^{0}C, 5 cm/min) ASTM D-113	cm	107	>100
Flash Point ASTM D-92(Cleveland open cup)	^{0}C	339	min. 232
Specific Gravity at 25 ^{0}C ASTM D-70	……	1.04	(1.01-1.05)

Table 5: Indirect Tensile Strength Test Results for Control Mixture and Asphalt Mixtures Modified by Crumb Rubber (CR No 50).

Sample		Polymer Percent (%)	Air Voids (%)	ITS (Mpa)
Unconditioned case	Control `Unmodified	0	4.08	2.177
	Modified with CR No 50	5	3.89	2.212
		10	3.97	2.415
		15	4.35	2.323
Conditioned case	Control `Unmodified	0	4.08	1.763
	Modified with CR No 50	5	3.89	1.883
		10	3.97	2.108
		15	4.35	`2.015

Table 6: Indirect Tensile Strength Test Results for Control Mixture and Asphalt Mixtures Modified by Methyl Methacrylates (MMA).

Sample		Polymer Percent (%)	Air Voids (%)	ITS (Mpa)
Unconditioned case	Control `Unmodified	0	4.08	2.177
	Modified with MMA	2.5	3.78	2.381
		5	3.56	2.501
		7.5	4.43	2.269
Conditioned case	Control `Unmodified	0	4.08	1.763
	Modified with MMA	2.5	3.78	2.048
		5	3.56	2.216
		7.5	4.43	`1.941

Table 7: Tensile strength ratio (TSR) Results for Control Mixture and Asphalt Mixtures Modified by Crumb Rubber (CR No 50) and Methyl Methacrylates (MMA).

Sample	Polymer Percent (%)	ITS_1 (Mpa) Unconditioned	ITS_2 (Mpa) Conditioned	TSR= $\frac{ITS_2}{ITS_1}$ (%)
Control `Unmodified	0	2.177	1.763	80.98
Modified with CR No 50	5	2.212	1.883	85.12
	10	2.415	2.108	87.28
	15	2.323	2.015	86.74
Modified with MMA	2.5	2.381	2.048	86.01
	5	2.501	2.216	88.60
	7.5	2.269	1.941	85.54

Table 8 : Regression Model Equation for the Polymer Effect on Tensile strength ratio (TSR) of Asphalt Mixtures.

Equation					R^2
$TSR = C_1 + C_2 \times PT + C_3 \times PP + C_4 \times AV + C_5 \times ITS_1 + C_6 \times ITS_2$					0.999
C_1	C_2	C_3	C_4	C_5	C_6
88.182	0.276	0.060	-0580	-33.182	30.090

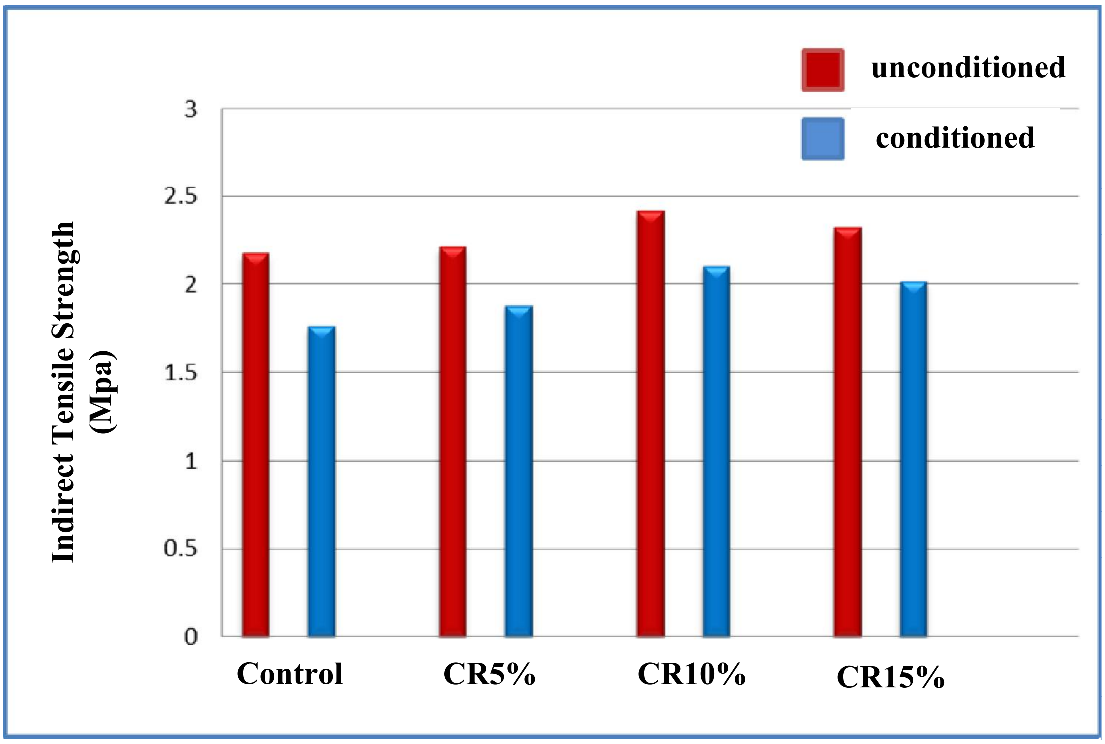

Figure 1: Effect Crumb Rubber Polymer (CR No 50) on the Indirect Tensile Strength (ITS) of Asphalt Concrete Modified Mixture.

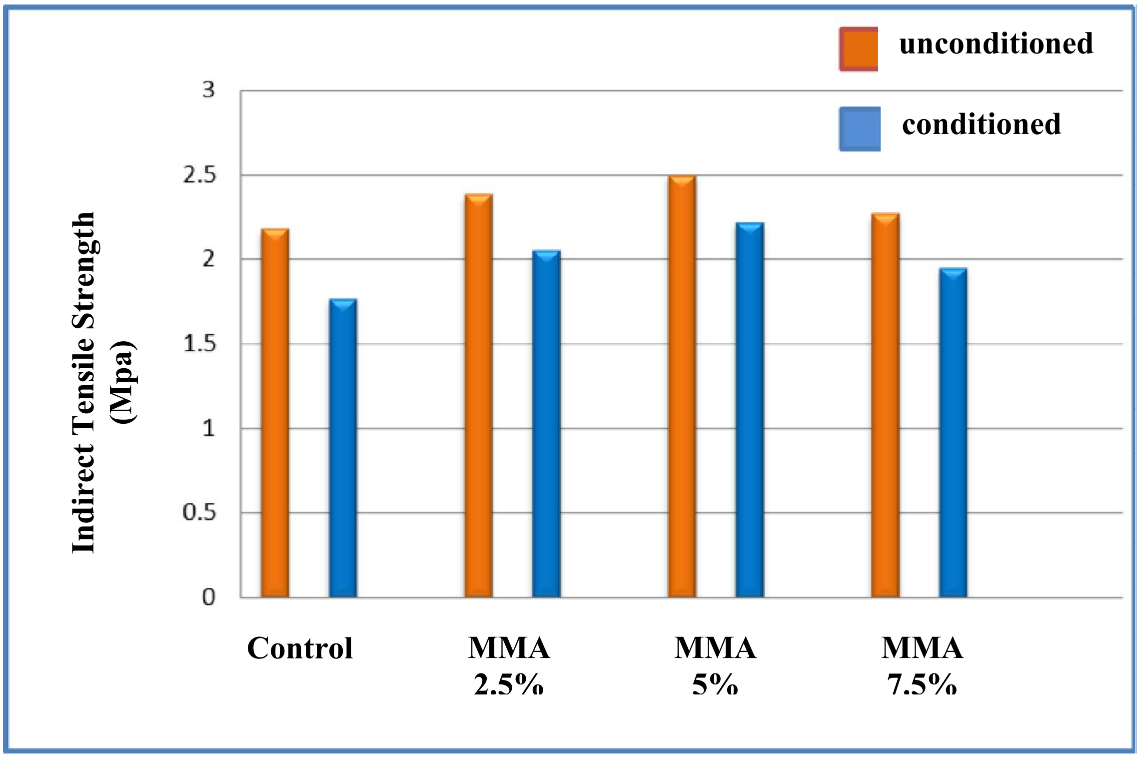

Figure 2: Effect Methyl Methacrylates Polymer (MMA) on the Indirect Tensile Strength (ITS) of Asphalt Concrete Modified Mixture.

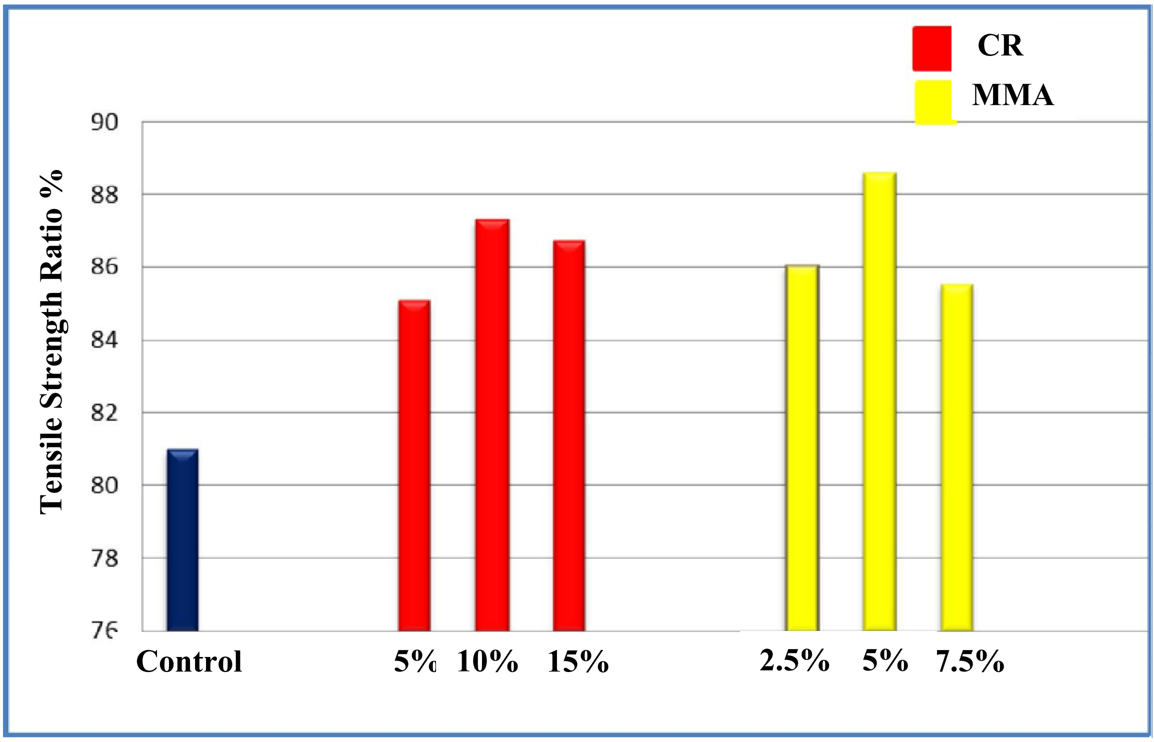

Figure 3 Effect Crumb Rubber Polymer (CR No 50) and Methyl Methacrylates (MMA) Polymer on the Tensile strength ratio (TSR).

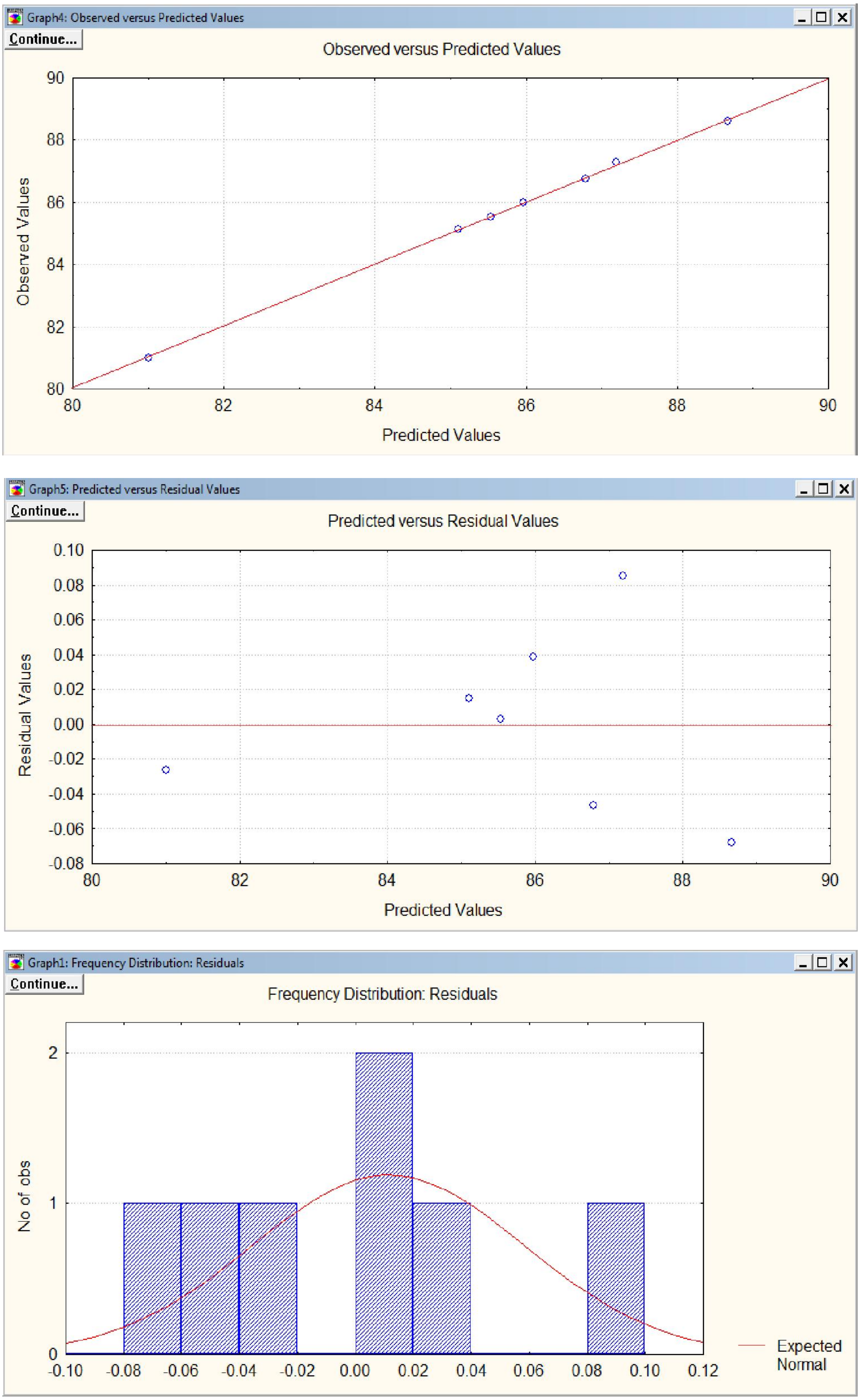

Figure 4: Diagnostic Plots of Model (TSR).