Wheel Track Test to Predict Permanent deformation (Rutting depth) of Hot-Mix Asphalt Pavements and Using Silica Fume to Reduce Effect of Permanent Deformation

اختبار عجلة المسار للتنبؤ بالتشوه الدائم (عمق التخدد) للتبليط بمزيج الأسفلت الساخن واستخدام مضاف غبار السيليكا لتقليل تأثير التشوه الدائم

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Abstract:

The road network of Iraq in the last two decades have increased in volume of traffic, heavy load and high temperatures. These reasons lead to the need for frequent and continuous maintenance work and the lack of funds allocated for maintenance work may lead to sudden rapid failure of performance of flexible asphalt concrete pavements which is evaluated by many constant factors. One of the major factors is the largest effect on the performance of flexible pavement which is the permanent deformation. The additives have showed acceptable effects on HMA at lower and higher temperatures due to increasing the resistance to permanent deformation (rutting). The main objective is evaluating the effect of additive on the resistance to permanent deformation of the hot mix asphalt (HMA). One type available additive which is Silica Fume with three various percentages was used. The percentages are (1%, 3%, and 5%) for Silica Fume by weight of asphalt binder. The experimental works in this research showed that additive - modified mixtures have rutting resistance, higher, than a control asphalt mixture at (50 Cº) about (30% - 60%) depending on different percentages of additive. It can be concluded that the concentration of Silica Fume (3%) gives the better properties of asphalt mixture to resist permanent deformation. A statistical model has been developed for the prediction of rutting depth in local asphalt paving materials as an influence by the factors of percentage of additive, and the number of passes at (50 Cº).

Key Words: Asphalt pavement, Permanent deformation, Silica Fumes, Wheel track device.

الخلاصة:

تأثرت شبكات الطرق في العراق وخلال العقدين الماضيين بسبب الزيادة في الحجوم المرورية والاحمال الثقيلة مع ارتفاع في درجات الحرارة. هذه الاسباب تؤدي الى ضرورة القيام بأعمال صيانة دورية باستمرار وبسبب قلة الاموال المخصصة للقيام بأعمال الصيانة قد يؤدي الى فشل سريع و مفاجأ في اداء التبليط المرن بالخرسانة الاسفلتية ويتم تقيم هذا الفشل بواسطة العديد من العوامل. احد هذه العوامل الرئيسية الذي له تأثير كبير على التبليط المرن هو التشوه الدائم. ان المواد المضافة لها اثار ايجابية مقبولة على خليط الخرسانة الاسفلتية عند درجات الحرارة المرتفعة و المنخفضة وتسبب زيادة في مقاومة التشوه الدائم (التخدد). ان الهدف الرئيسي هو تقيم تأثير المادة المضافة على مقاومة التشوه الدائم لخليط الاسفلت الساخن المرن (HMA). تم استخدام نوع واحد من المضافات هو غبار السيليكا واستخدم ثلاث نسب مختلفة من هذا المضاف. وهذه النسب هي كالاتي (1 %, 3 %و 5 %) من غبار السليكا كنسب وزنية من الاسفلت المستخدم. وتبين الاعمال التجريبية في هذا البحث ان الخليط المعدل بالمضاف له مقاومة للتخدد، اعلى من مقاومة الخليط الاعتيادي التقليدي ذو الاسفلت الغير معدل وتتراوح بحوالي من (30 % -60 %) عند درجة حرارة (50 درجة مئوية) وتعتمد على نسبة المضاف المستخدم. ونستنتج ان نسبة تركيز(3%) من غبار السيليكا يبين خصائص افضل للخلطة الإسفلتية لمقاومة التشوه الدائم. وقد تم تطوير نموذج احصائي للتنبؤ بعمق التخدد للتبليط بخرسانة الأسفلت للمواد المستخدمة المحلية وتأثير استخدام نسب مختلفة من المضاف وعدد مرات مرور عجلة المسار عند درجة حرارة معينة هي (50 درجة مئوية).

الكلمات الدالة :التبليط الاسفلتي، التشوه الدائم، غبار السيليكا، جهاز عجلة المسار.

1- Introduction:

The permanent deformation (rutting) is the one of distress in asphalt pavements and it is the collection of rutting asphaltic layer deformation, that occur under the wheel pathway of the vehicle, especially when the degree of temperature is as high as in a hot climate or during the season of summer days of moderate state, **[1]**. Also rutting occurs when the pavement under high traffic consolidates of loading and there is a lateral movement of the hot mix asphalt (HMA). Generally, shear failure came from lateral movement occurs in the top portion of the pavement surface, as a result of permanent deformation, the service life of pavement is reduced, **[2]**. During the diverse years ago, many problems with the amount and severity of the rutting (permanent deformation) in hot mixture of asphalt pavements had appeared. This problem with (permanent deformation) is attributed by an increase in vehicle tires pressure, volume of traffic, and axle loads, **[3]**. Bitumen (asphalt) mixture be modified by adding a various type of additives, the addition of additives typically increases the stiffness of the asphalt binder and improves temperature susceptibility. Increase stiffness, improves the permanent deformation resistance of the asphalt mixture in the hot season, and allows the use of relatively flexible base asphalt binder, which in the role, modified asphalt to also show improved cohesion and adhesion of properties, **[4]**. Hamburg city, Germany, based on a similar British apparatus that had a rubber tire, originally developed (Hamburg wheel tracking apparatus) in year 1970, **[5]**. (Helmut-wind), of Hamburg, finalized the test method and developed the specification to measure permanent deformation (rutting), **[6]**.

2- Objectives:

In this research three objectives were drawn:-

1. Evaluating the effect of Silica Fume on the ability of mixture resistance to permanent deformation by using wheel track test, and comparing these properties with control mix unmodified asphalt mixture.
2. Evaluating modified binders provide that given better properties and, the amount of additive Silica Fume should be used for getting better pavement of asphalt performance.
3. Prediction a statistical model for (Permanent Deformation) in asphalt concrete of mixture.

3- The Used Materials in This Research:

3-1 Aggregates:-

The coarse aggregate is used in this work is crushed aggregate brought from (Kerbala quarries). This aggregate is commonly used in the middle region of Iraq for asphalt concrete pavement mixture. The surface color of particles tends to the white color with angular edges. In the other hand, fine aggregate was obtained from (Kerbala quarry). Both (coarse & fine aggregates) used in this experimental work were sieved and recombined in the proper proportions to reach to the surface gradation (TypeIII A) as required by (The SCRB Specifications), **[7]**. Routine tests were done on the aggregates (coarse & fine) to evaluate their physical properties. The results of the specification limits for aggregate as set by the (SCRB) are summarized in (Table1). The selected aggregate gradation with specification limits for Surface Course are presented in (Table2).

3-2 Asphalt:-

The typical asphalt binders in Iraq according to the suggestion of Abbas, which is used for construction of asphaltic pavements has performance graded of asphalt binder (PG 70-16), the asphalt with a penetration grade (40-50) is equivalent to (PG70-16), **[8]**. The physical properties and tests of asphalt binder are presented in (Table3).

3-3 Filler:-

One type of mineral filler (Portland Cement) is used in this work, brought from (Cement Factory of Kerbala).

3-4 Additive:-

In this research, one type of additive is used Silica fumes, it is obtained from local markets in Iraq, it's collected by filtering the escaping gases from the furnaces. A vapor phase hydrolysis process using produces Silica Fumes is used to modify asphalt binders, **[9]**. Two asphalt binders (PG 70-16) (modified and unmodified binders) used in this study were prepared by a supplier from the same asphalt. The modified asphaltic binder is prepared by adding three percentages of the Silica Fumes (1%, 3%, and 5%) by weight of asphalt binder. The some physical properties of Silica fumes are specific surface (15,000–30,000 (m2/kg)) and specific gravity (2.22).

4-Laboratory Sample Preparation and Test Methods:

4-1 Sample Preparation:-

For the wheel track apparatus test, sample (150mm) in diameter and (60mm) in height with 4% air void (AV%) contents were prepared in the laboratory by using the compaction device (Marshall compacter) depending on the relationship between air voids and the number of blows to select the optimum number of blows in agreement with (4% AV). For the Marshall method test, sample (100mm) in diameter and (60mm) in height were prepared by using the device of compaction to have (4%AV) of contents depending on specification of (SCRB).

4-2 Marshall Test:-

This test was carried out according to the Prior to stability test, flow test and percent of air void test, **[10]**, is determined for each specimen. Method of Marshall test was used to find the optimum asphalt content of asphalt concrete mixture specimens. The results of Marshall tests showed almost typical relationships between Marshall properties and percentage of asphalt content. Four percentages were used in this study (4%, 4.5%, 5%, and 5.5%) of Daurah (PG 70-16) asphalt binder was used, with ordinary Portland Kerbala cement as a (filler), and aggregates were obtained from AL- Kufa factory and one gradations of aggregate for ((12.5mm) nominal maximum of size) for aggregate accordance with the SCRB specification (R9), for surface course (TypeIII (A)), **[7]**. Optimum asphalt content (O.A.C) of the different mixtures was determined from Marshall curves, ((Marshall stability), (Marshall flow) and ((4%) percentage of air voids)) which are shown in (Figure1), the (O.A.C) is found to be (4.9%).

4-3 Wheel Track Device Test:-

Wheel Tracker device was used for test provides information about the permanent deformation (rutting) by using a moving concentrated load. One wheel apply 158 pounds about (710 newton) of pressure at the contact points and pass on repetitively over the specimen. This test was conducted in dry condition to 5000 passes (2500 cycles) at 50˚C, where the rutting depth is measured continuously. This test is conducted two cylindrical specimens for control mix at the same time and compacted with the Marshall compacter device. In case that wheel is a compilation of the 5000 passes at 50˚C, the testing was manually stopped and rutting depth is record by using digital measurement tool, From (Figure2) that showing the sample will failure or occurs max permanent deformation (rutting depth) at stripping inflection point (SIP) in which must stop the test. Results are expressed in the (Table4), one test at temperature 50 Cº, max rutting depth occurs at 5000 cycles (10000) passes, **[11]**.

5- Results and Discussion:

5- 1 Results of Wheel Track (WT) Test:-

The results of (WT) test are presented in (Table5), they indicate that the modified asphalt mixtures by adding Silica Fumes has a higher resistance to rutting depth (permanent deformation) than the mixture without additive (control mixtures). The effects number of wheel passes and concentrations percentage of additives is shown in (Figure3). The modified mixtures by adding (1% Silica Fumes) at (50 Cº and 5000 passes) have permanent deformation of (4.87mm), but for modified mixture by adding (3% Silica Fumes) at (50 Cº and 5000 passes) have permanent deformation of (2.31mm) and also, when adding (5% Silica Fumes) at (50 Cº and 5000 passes) have permanent deformation of (3.24mm). The highest resistance to permanent deformation (rutting depth) is recorded for asphalt mixture by adding (3% Silica Fumes) for various numbers of wheel passes when compared with other modified mixture by adding (1% Silica Fumes & 5% Silica Fumes).

5-2 Results of Regression Predict Modeling for Rutting Depth:-

One model derived by using a computer program (Statistica(V5.5)). In this program, there are two methods generally used to assess the adequacy of proposed regression predict model for rutting, the first method depended on examining (R^2) goodness of the fit measure by analysis of data, while the second method is based on the graphical analysis, **[12]**. This method called diagnostic of plots as shown in (Figure4). The model of (rutting depth) derived from the analysis of data is found:

RD = C1 + C2 × PP + C3 × NP + C4 × PP^2 + C5 × NP^2 + C6 × exp (PP/NP)^2 -----(5-1)

R^2 = 0.972 ----------------------------- R = 0.985

Where:-

RD : Rutting depth (mm).

PP : Percent by weight of additive Silica Fumes from (%asphalt).

NP : Number of passes for wheel track.

Coefficient : (C1= -2.44×10^{2}, C2= -0.021×10^{2}, C3=0.141×10^{-2}, C4=27.40×10^{-2},C5=0.83×10^{-7} , C6=2.46×10^{2}).

6- Conclusions:

1. The permanent deformation under wheel track (WT) test results show less rutting depth for modified asphalt of mixtures when compared with control asphalt mixtures. Also, the use of additive for modified asphalt concrete of mixtures caused increase in resistant mixture to permanent deformation about (30% - 60%) at temperature (50°C).
2. Best values to resist permanent deformation and enhanced the performance mixtures of asphalt, can be obtained from modified mixtures by adding (3%Silica Fumes).
3. One model is developed depending on (Statistica program) to estimate the permanent deformation, The model is shown below :-
   RD = C1 + C2 × PP + C3 × NP + C4 × PP^2 + C5 × NP^2 + C6 × exp (PP/NP)^2

7- References:

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Table (1): Physical Properties of Aggregate.

Property	ASTM Designation	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 C-128	2.52	2.61
Apparent Specific Gravity	C-127 C-128	2.66	2.67
% Water Absorption	C-127 C-128	3.14	2.80
% Wear (Los Angeles)	C-131	30 Max 35%	-----
Percentage of Fractured Particles	D 5821	94%	-----

Table (2): Asphalt Mixture Grading for Surface Course (TypeIII A).

Sieve		(% Passing by Weight of Total Aggregate + Filler)	Specification Limits for Surface Coarse (SCRB),Type IIIA
Opening (mm)	Size (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)		4,9	4 - 6

Table (3): Physical Properties of Asphalt Binder.

Tests	Units	Penetration Grade (40-50)	S.C.R.B Specification
Penetration (25 ^{0}C), 100 gm, 5sec) ASTM D-5	1/10 mm	47	(40-50)
Kinematic Viscosity at 135 ^{0}C ASTM-2170	cst	384	-----
Ductility (25 ^{0}C, 5 cm/min) ASTM D-113	cm	106	>100
Flash Point ASTM D-92(Cleveland open cup)	^{0}C	337	min. 232
Specific Gravity at 25 ^{0}C ASTM D-70	……	1.02	(1.01-1.05)

Table (4): Effect of Number of Passes on Permanent Deformation (Rutting Depth) for Control Mix at (50˚C).

Sample	Number of Passes	Rut Depth (mm)
Control Mixture	0	0
	1000	2.81
	2000	3.90
	3000	4.85
	4000	5.79
	5000	6.91
	6000	8.65
	7000	10.50
	8000	12.38
	9000	14.47
	10000	16.55

Table (5): Wheel Track Test Results at 50 Cº for Control Mixture and Asphalt Mixtures Modified by Silica Fumes with Three Different Percentages.

Sample	Number of Passes	Rut Depth(mm) at (50˚C)
Control `Unmodified	1000	2.81
	3000	4.85
	5000	6.91
Modified with Silica Fumes (1%)	1000	1.39
	3000	3.12
	5000	4.87
Modified with Silica Fumes (3%)	1000	0.88
	3000	1.78
	5000	2.31
Modified with Silica Fumes (5%)	1000	1.16
	3000	2.19
	5000	3.24

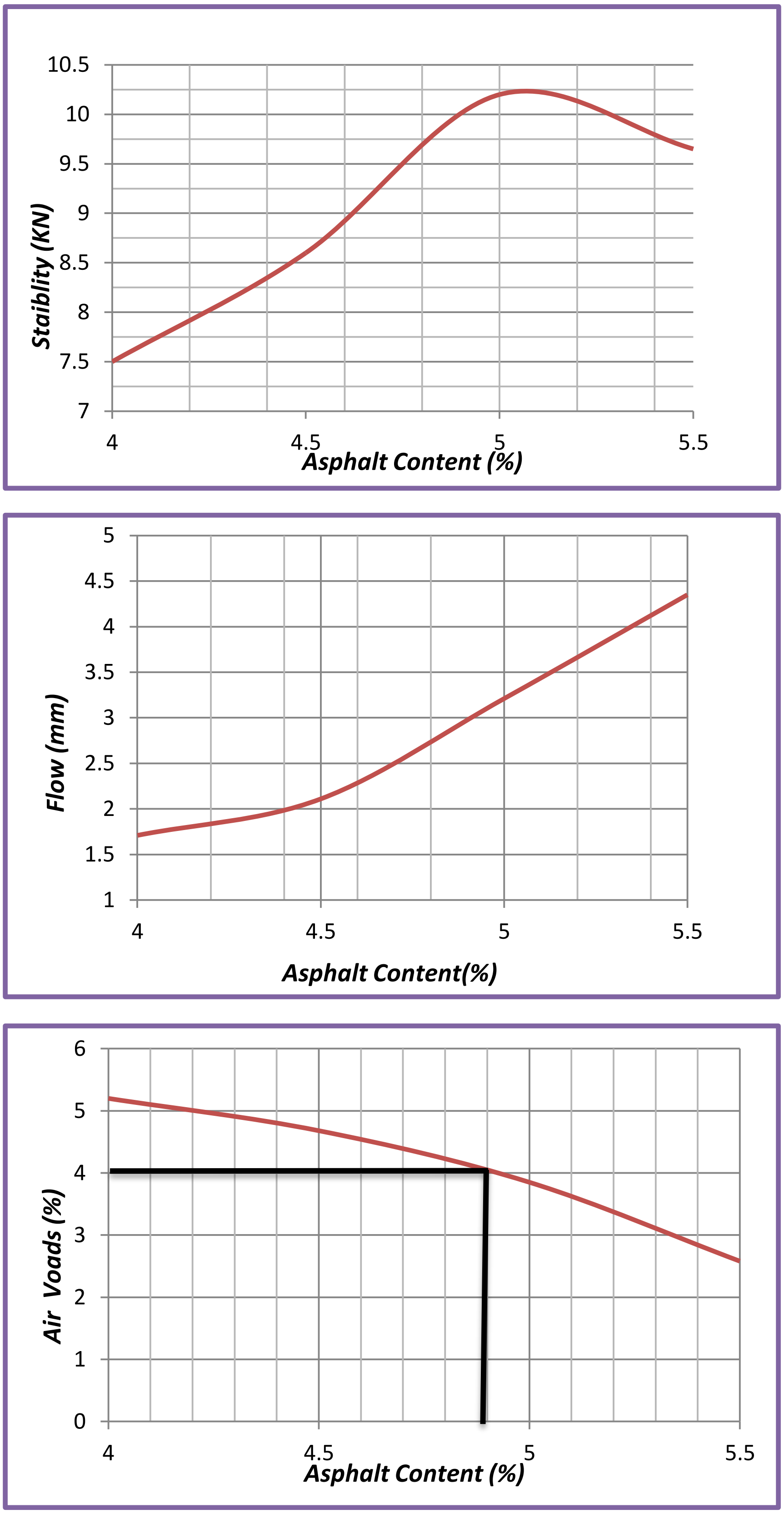

Figure (1): Marshall Mix Design Curves for Optimum Asphalt Content.

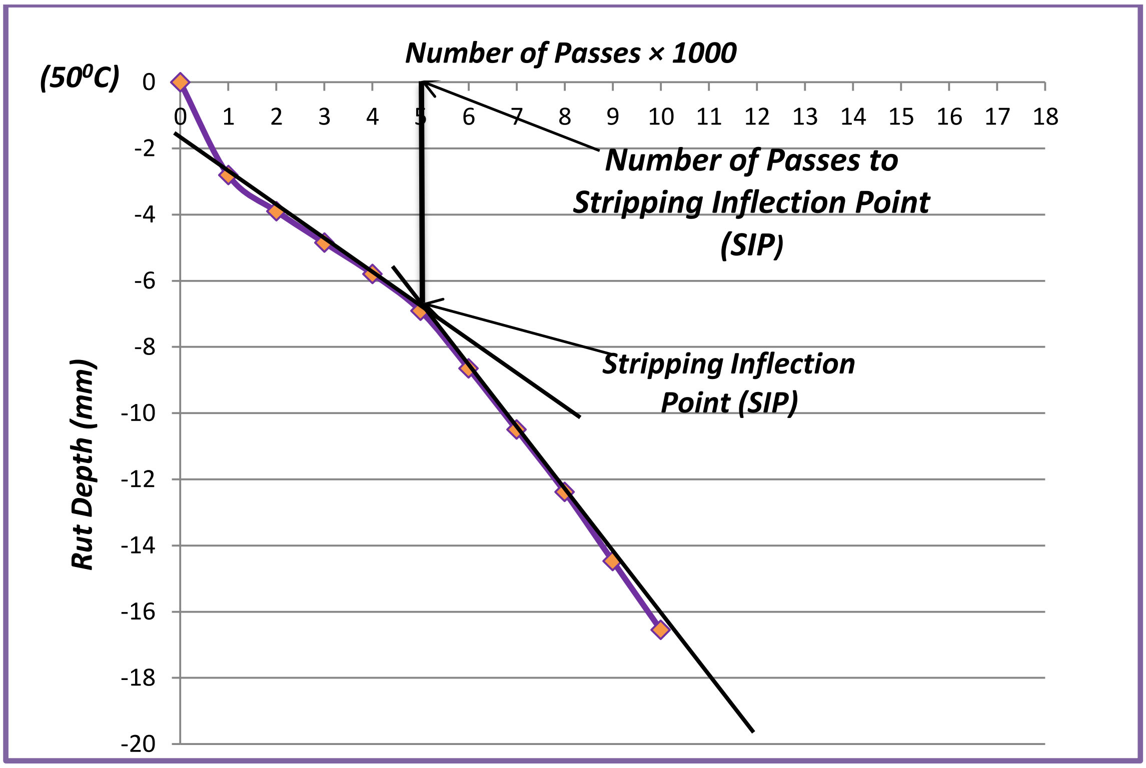

Figure (2): Wheel Track Device Curve for Control Mix Test Parameter at (50 Cº).

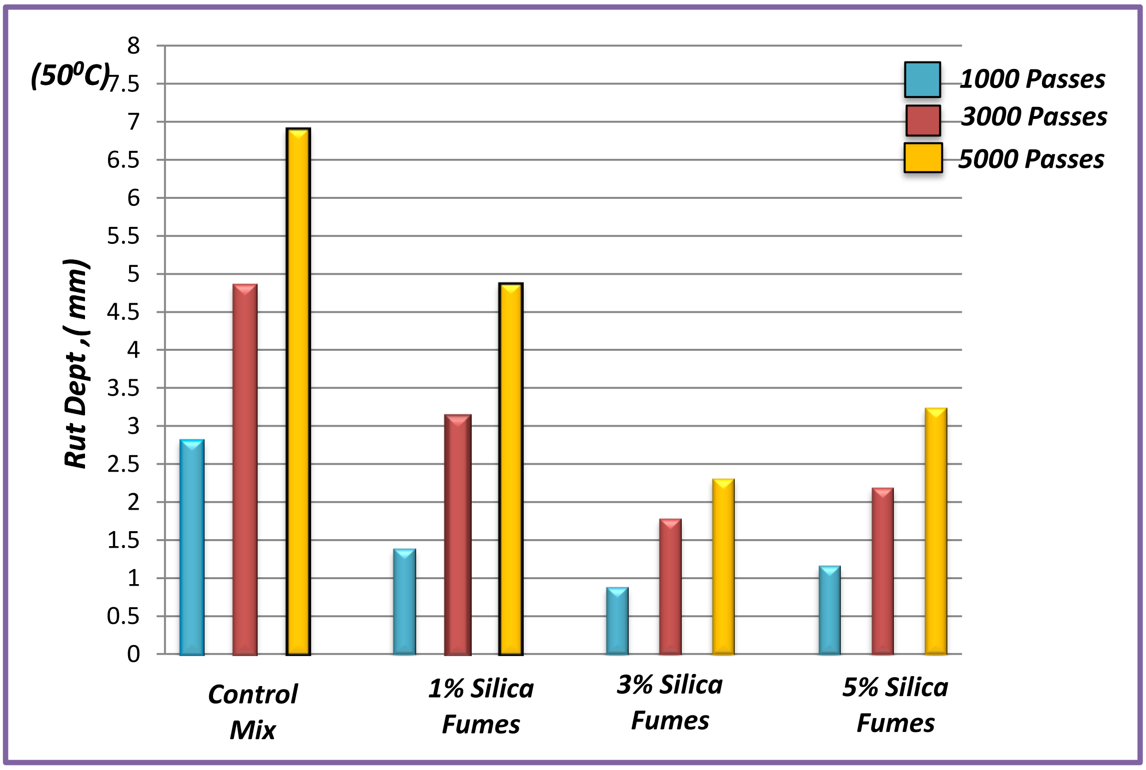

Figure (3): Wheel Track Test Results for Control Mix & Asphalt Mixtures Modified by Silica Fumes at (50˚C).

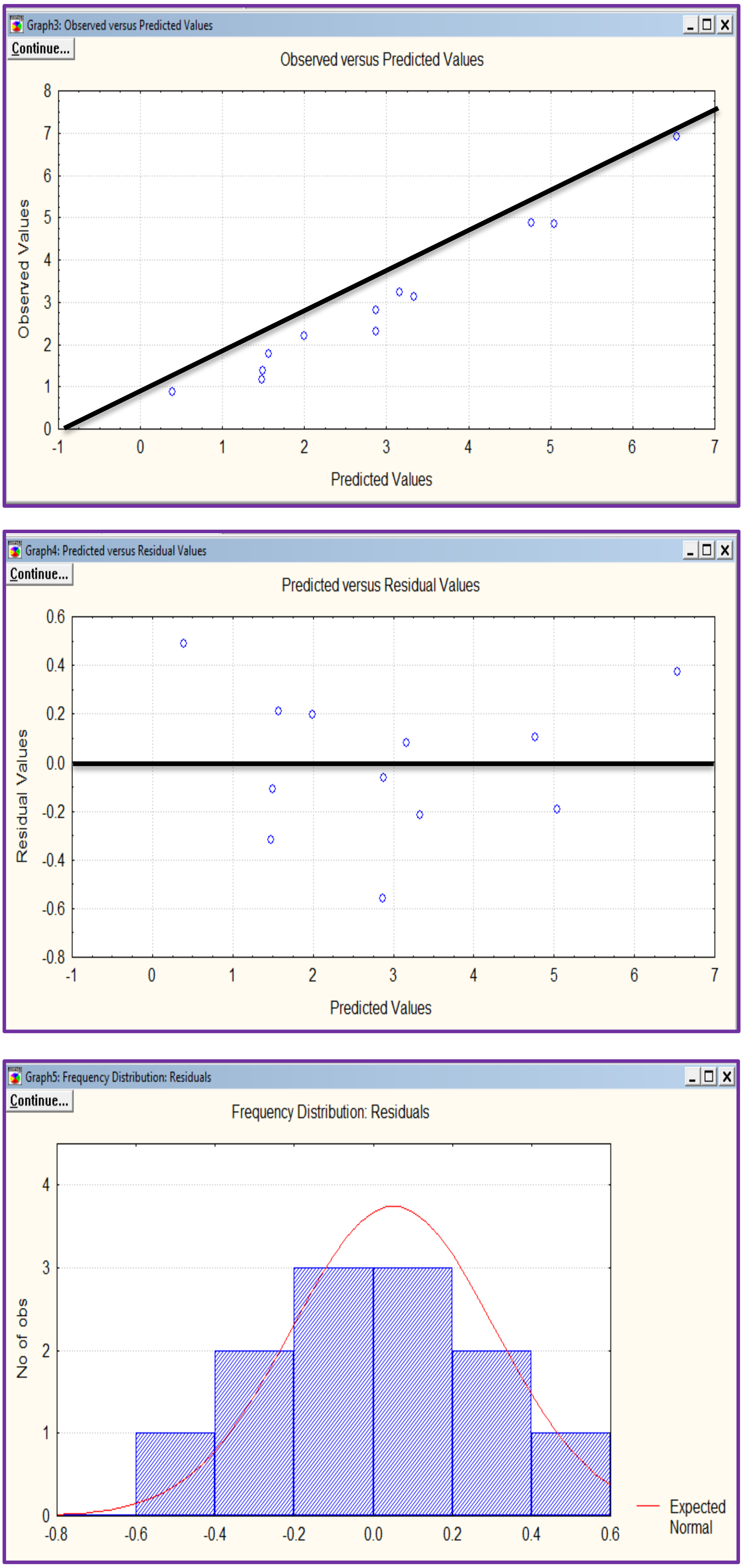

Figure (4): Diagnostic Plots of (Rutting Depth) Model.