Contributory Factors Related to Permanent Deformation of Hot Asphalt Mixtures

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ABSTRACT

Permanent deformation (Rutting) of asphalt pavements which appears in many roads in Iraq, have caused a major impact on pavement performance by reducing the useful service life of pavement and creating services hazards for highway users. The main objective of this research is investigating the effect of some contributory factors related to permanent deformation of asphalt concrete mixture. To meet the objectives of this research, available local materials are used including asphalt binder, aggregates, mineral filler and modified asphalt binder. The Superpave mix design system was adopted with varying volumetric compositions. The Superpave Gyratory Compactor was used to compact 24 asphalt concrete cylindrical specimens. To collect the required data and investigate the development of permanent deformation in asphalt concrete under repeated loadings, Wheel-Tracking apparatus has been used in a factorial testing program during which 44 slab samples; with dimensions of 400×300×50 mm; were tested to simulate actual pavement. Based on wheel-tracking test results, it has been concluded that increasing the compaction temperature from 110 to 150ºC caused a decreasing in permanent deformation by 20.5 and 15.6 percent for coarse and fine gradation control asphalt mixtures respectively. While the permanent deformation decreased about 21.3 percent when the compaction temperature is increased from 110 to 150ºC for coarse gradation asphalt mixtures modified with styrene butadiene styrene SBS with 3 percent by asphalt binder weight.

Keywords: modified asphalt, asphalt concrete; Superpave; rutting performance; and wheel tracking test.

العوامل المساهمة والمتعلقة بالتشوه الدائمي للخلطات الاسفلتية الحـــارة

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الخلاصـــة

ان التشوهات الدائمية (التخدد) في التبليط الاسفلتي تظهر في العديد من طرق العراق ، وتسبب تأثيرا رئيسياً على أداء التبليط وذلك عن طريق تقليل العمر الخدمي للتبليط وجعل استخدام هذه الطرق محفوفة بالمخاطر . ان الهدف الرئيسي من البحث الحالية هو تقييم تاثير بعض العوامل المتعلقة بالتشوهات الدائمية للخلطة الاسفلتية الكونكريتية. لتحقيق الهدف في هذا البحث فقد تم استخدام المواد المتوفرة من الإسفلت والحصى والمواد المالئة والمضافات التي تشمل الاسفلت المحسن .كما أُعتمدت طريقة التبليط عالي الاداء في التصميم وحساب مختلف الخصائص الحجمية واستخدم جهـازالرص الدوراني في رص 24 عينة اسطوانية من الخرسانة الاسفلتية. من اجل توفير البيانات المطلوبة والتحري عن التشوهات الدائمية في الخرسانة الاسفلتية ، تم استخدام جهاز العجلة المسارية لتسليط الاحمال المتكررة ، تم اعداد 44 بلاطة من الخرسانة الأسفلتية تم فحصها لتمثيل واقع التبليط. اعتمادا على نتائج الفحص تبين بان زيادة درجة حرارة الحدل من 110 م الى 150 °م قلل من التشوهات الدائمية بمقدار 20.5 و 15.6كنسبة مئوية للركام الخشن والناعم للخلطات الاسفلتية التقليدية. بينما قلت التشوهات الدائمية بمقدار 21.3بالمئة عند زيادة درجة حرارة الحدل من 110 م الى 150 م للركام الخشن والناعم للخلطات الاسفلتية المحسنة بمادة الستايرين بيوتادين ستايرينSBS المضافة كنسبة 3 بالمئة من وزن الاسفلت الرابط.

1. INTRODUCTION

Permanent deformation (rutting) of asphalt pavements has a major impact on pavement performance. Rutting reduces the useful service life of the pavement. By affecting vehicle handling characteristics, it creates serious hazards for highway users; two major elements contribute to asphalt pavement deterioration, the gradual effects of weathering and the action of vehicle traffic, **Huang, 1993** and **Pavement Design Manual**, **2015**.

Early detection and repair of pavement defects is the most important preventive maintenance procedure. There are five areas of distress for which guidance is needed: fatigue cracking, (wheel path) rutting, thermal cracking, friction, and moisture damage, all of these distresses can result in loss of performance, but rutting or permanent deformation is one of distress that is most likely to cause a sudden failure as a result of unsatisfactory hot mix asphalt or asphalt mixture, other distresses are typically long term failures that show up after a few years of traffic, **Ishai**, and **Craus, 1996**.

Recently, Superpave has been reported as an improved system for performance based design, analysis of asphalt concrete mixes and asphalt pavement performance prediction. It is a structured approach consisting of selection of materials, selection of design aggregate structure, asphalt binder content, and evaluation of moisture susceptibility, **Khan,** and **Kamal, 2012**.

In Iraq, the severity of rutting has been increased in asphalt pavements possibility due to the increase in truck axle loads, tire pressure, and high pavement temperature in summer, as shown in **Fig. 1**.

2. RESEARCH OBJECTIVE

The main objectives of the research is to study the main factors affecting rutting in asphalt concrete mixture in Iraq such as; mix properties, types of filler, loading and temperature conditions by using Superpave mix design system and study the effect of additive on the improvement of asphalt concrete mixes against the permanent deformation .

3. LABORATORY TESTING

3.1 Material

To meet the objectives of this research, available local materials were used including asphalt binder, aggregates and mineral filler. Asphalt binders (40-50 or PG 64-16) was obtained from Al-Daurah refinery in Baghdad and the aggregate from Al-Nibaie quarry in north of Baghdad whereas the mineral filler was brought from lime factory in Karbala Portland cement is from Kubbesa factory which was obtained from market. The aggregates are sieved and recombined in the proper proportions to meet the wearing course gradation as required by **SCRB specifications, 2003**. A 19 mm aggregate maximum size gradation is used in this research. The fractions of aggregate are separated into 9 sizes, as retained on each of the following sieves, 3/4", 1/2", 3/8", No.4, No.8, No.16, No.30, No.50, and No. 200) using dry sieve analysis. Mineral filler (Limestone, Portland cement) has been added according to the desired gradations requirements. The gradation curve for the aggregate is shown in **Fig. 2**; four lines are presented: the upper , the lower curves of the Iraqi specifications of SCRB in addition to the controls points of Superpave system, **Table 1** shows the physical prosperities of asphalt binder .

In this research the Superpave mix design system was adopted with varying volumetric composition. The Superpave Gyratory Compactor was used at the NCCLR to prepare 24 asphalt concrete cylindrical specimens for carrying out volumetric design according to Superpave system, **AASHTO Designation: T 312-2010**. The optimum asphalt content for the selected asphalt binder and selected aggregate gradation was 4.6 percent for conventional coarse asphalt mixtures, while it is about 4.9 percent for SBS modified asphalt mixtures.

3.2 Sample Preparation

The roller compacter apparatus can compact asphalt slabs to a target density using loads per unit roll width about 5-10 ton, which are consistented to those of pavements rollers used in the highway construction. The roller compactor provides a pneumatically powered means of compacting slabs of asphaltic material in the laboratory under conditions, which simulate in-situ compaction.

In this research, compacted asphaltic slabs for rutting testing are prepared at air voids equal to (4%) using Roller Compactor Device at NCCLR according to (EN12697-Part 33:2003) and Superpave system, **AASHTO Designation: T 312-2010**. The dimensions of the compacted slabs used in this work are of (400 mm by 300 mm by 50±6 mm) as proposed by **EN 12697-Part 22:2003.**

Proportion of aggregate and asphalt binder are used for mixing, curing, and compacting. The aggregate retained on the 3/4" sieve is discarded. Mineral filler (Limestone) and cement have been added according to the desired gradations requirements. The aggregate is combined into batch of (13400 gm for slab specimen) on the mixing bowl and heated to the mixing temperatures prior to mixing with asphalt binder which heated to the mixing temperatures corresponding to each binder, as shown in **Fig. 3**.

For the modified binder preparation, the asphalt cement for convention mixture is heated in the factory oven to the temperature of mixing prior to adding the specific 3 percent amount of SBS additive, this percent is chosen according to previous researches prepared by the Ministry of Industry and Minerals, it is preheated in an external oven until liquid at 180 ºC, the desired weight of additive which is determined by multiplying it's percent by the required weight of asphalt content was added gradually and mixed until getting homogenous binder.

The aggregate and asphalt are mixed in mixing bowel on hot plate for three minutes until asphalt had sufficiently coated the surface of the aggregates or until a homogeneous mixture is achieved, as shown in **Fig. 4** . The asphalt-aggregate mixture is then short term oven aged for 2hrs at 135°C for the determination of the maximum specific gravity and 4hrs at the same temperature for compaction in according with **Asphalt institute, 1996**. This aging represents the aging that occurs in the field between mixing and placement and allows for absorption of the asphalt binder into the aggregate pores. The mix is stirred every 30 minutes during the short-term aging process to ensure uniform aging throughout the mix.

Compaction is then performed using the Roller Compactor in accordance with EN 12697-33, the mold and the plates are heated in the oven at the specified compaction temperature to ensure that the mix temperature is not reduced. The load is from 7-10 KN which applied on the specimens to achieve proper compaction and sufficient air voids, as shown in **Fig. 5** and **Fig. 6.**

3.3 Wheel-Tracking Testing

The Pavement Wheel Tracker is a device for testing the wear ability of asphalt mixes by simulating roadway conditions, the test is performed according to **EN 12697-22, 2003** and **AASHTO Designation: T 340, 2010**. The test provides information about the rate of permanent deformation from a moving, concentrated load. It uses a Linear Value Displacement Transducer (LVDT's) to measure the deformation of the specimen. The loaded wheel applies about 700 N (158 pounds) of load at contact points and passes repetitively over the sample for up to 10,000 cycles. Test results are compiled in a Microsoft Access database application which provides several means of reporting results.

Wheel-tracking machine ; as shown in **Fig. 7;** is constructed so as to enable the test specimen in its cradle to be moved backwards and forwards under the loaded wheel in a fixed horizontal plane. The center-line of the tire track is (5 mm) from the theoretical center of the specimen. The center of the contact area of the tyre describes a simple harmonic motion with respect to the center of the top surface of the test specimen with a total distance of travel of (230±10) mm and a constant loading frequency of (26.5±1.0) load cycles per 60 seconds for the test device in approximately 10,000 load cycles or 20 mm maximum allowed deformation is reached.

The experiment design for the permanent deformation testing is a full factorial with; two asphalt contents, three compaction temperatures, two asphalt types: original and modified with SBS and two types of gradations, resulting in a nominal total of 24 slab tests.

The compacted specimens, which are 30 cm in width, 40 cm in length and 5 cm in height, are cooled to room temperature for a period of 24 hours in accordance with (EN-12697-22). The specimens are placed in mold and then placed in on the carriage table of WTD for testing. The specimens in the mold are labeled with information mix type.

The holder of the displacement transducer is disengage and reference plate is adjust in order the transducer probe is compressed approximately 70% of its total travel. This allowed having sufficient travel available to measure the track formation on the sample. Starting the software, supplied with the machine, and entering the required test information into the computer. The testing device automatically stops the test when the device applies the number of desired passes or when reaching the maximum allowable rut depth, as shown in **Fig. 8.**

If the maximum allowed deformation is reached before 10,000 passes, the wheel is lifted off the failed sample. Test results are compiled in a Microsoft Access database application which provides several means of reporting results.

Finally at the end of the test the arm will return automatically to its upper position while the display will show the results of the test which can be saved in the archives and/or transmitted to an external computer.

4. RESULTS AND ANALYSIS

Permanent deformation and vertical permanent strain (εp) were measured at testing temperature of 40°C, and frequency level 53 passes per minute, and two selected compaction temperatures of 110^{o}C and 150^{o}C and two asphalt contents are used and two types of gradation with two types of filler are used , SBS polymer was used as modifier to asphalt binder .

4.1 Effect of Compaction Temperature

This research investigates the influence of compaction temperature on coarse and fine asphalt mixes for modified and unmodified binders.

For this, Superpave mix designs for two compaction temperatures of 110 °C and 150 °C and two asphalt binders (control, 3% styrene butadiene styrene (SBS) modified) were carried out. A total of 24 specimens were manufactured with a short-term aged for 2 h at the mixture compaction temperatures prior to test.

Fig. 9 shows effect of compaction temperature on Permanent deformation (i.e. rut depth, RD). It can be seen that permanent deformation decreased when compaction temperature change from 110 to 150 ºC as shown in **Table 2**. It can be related to shear susceptibility of mixtures and it's sensitive to temperature changes. The rut depth (RD) decreased about 20.5 and 15.6 percent when the compaction temperature is increases from 110 to 150 ºC for coarse and fine gradation control asphalt mixtures respectively as shown in **Fig. 9**. While the rut depth (RD) decreases about 21.3 percent when the compaction temperature is increases from 110 to 150 ºC for coarse gradation SBS modified asphalt mixtures as shown in **Fig. 10**.

The results from this study showed that the compaction temperatures significantly affected the volumetric properties of the SBS modified mixes. The mixtures containing SBS-modified binders, the rut depth decreased by 21.3 percent and the air–void contents significantly decreased with an increase in compaction temperature because the binder in modified asphalt mixtures is stiffer than in conventional mixtures; therefore, there is a need for a higher compaction temperature

4.2 Effect of Asphalt Content

Based on the data shown in **Fig. 11** to **13**, it appears that the examined asphalt content has influence on the plastic response of the material. The plastic strain is increased with the increases in asphalt content from optimum AC to opt. +0.5 percent asphalt content for conventional and modified asphaltic mixtures. For (RD) value, it can be found that it increases about 10.6 percent when asphalt content increases from 4.6 to 5.1 percent for conventional coarse asphalt mixture, while it increased about 8 percent when asphalt content from 4.9 to 5.4 percent for SBS modified asphalt mixture, as shown in **Table 3.**

It can be concluded for Superpave mixtures, the total asphalt content plays an important significant role in controlling overall rutting resistance of the conventional and modified asphaltic mixtures, i.e. rutting performance is highly influenced by total asphalt content , voids in mineral aggregate (VMA), voids filled with asphalt , (VFA), and dust-to-binder ratio.

4.3 Effect of Aggregate Gradation

Aggregate presents major portion of asphalt concrete. It was found that researchers have come to different conclusions with regard to the effect of aggregate gradation on resistance to rutting of asphalt mixtures.

Two gradations of aggregate that are typically used to produce hot mix asphalt in Iraq were used in this research. They are: coarse and fine gradation, one of them passing below the restricted zone (on the Superpave gradation chart) and the other above the restricted zone. **Fig.14** shows the results showed effect of aggregate gradation of mixture on permanent deformation, it concluded that rutting resistance of asphalt paving mixes is affected by the mix gradation of aggregate. Coarser gradation had higher resistance to rutting from fine gradation of aggregate by 65.6 percent.

4.4 Effect of Type of Filler

The resistance of asphalt mixture to permanent deformation is related to the stiffness of asphalt binder, mixture volumetric, and the bonding interaction between asphalt binders and aggregate. Mineral filler is usually added into asphaltic mixture to stiffen asphalt binder and improve asphaltic mixture density and strength. These fillers are typically fine powders with particle sizes in the range of 0–100 µm, two types of filler were used in this research, there are: limestone and cement.

However, the properties of mineral fillers of the compacted mixtures can influence on the permanent strain for conventional and modified mixtures as depicted in **Fig. 15**. The percentage of change in in Permanent Deformation is presented in **Table 4.** It can be observed that the rut depth (RD) decreases about 23.5 and 30.6 percent when the cement filler is used in asphaltic mixtures instead of limestone filler for coarse and fine gradation mixtures respectively. The effect of type of filler on the mixture rutting potential was more significant for the fine mixture than the coarse mixture.

4.5 Effect of SBS Polymer additive

During the preparation of the samples it was noted that the mixes with the polymer-modified binder were more difficult to mix and compact. Any cooling of the mix greatly increases the viscosity of the asphalt and the stiffness of the mix.

In this research, the addition of additive (SBS) polymer tends to improve the mix properties. In Superpave mix design, the results showed that rutting performance of the asphaltic samples has improved for the polymer modified cases.

The percentage of change in permanent deformation with Polymers Content is presented in **Table 5.** It can be observed that the permanent displacement (RD) decrease about 37.22 and 29.5 percent when SBS polymer is used for coarse and fine gradation mixtures respectively, as shown in **Fig. 16**.

Based on the above evaluation, the use of asphalt modified by SBS polymers gives the coarse wearing course better rutting resistance than the fine gradation of the same asphalt performance grade.

At the testing temperature of 40°C±5, the asphaltic mixtures appeared to maintain stiffness levels. However, it should be noted that when SBS polymer modifier is used, the HMA become stiffer at the high testing temperature. It can be concluded that SBS polymer-modified binder made the polymer modified mixtures stiffer than control mixes with unmodified asphalt binder at high temperature.

5. CONCLUSIONS

Considering all results of laboratory tests and analysis, the following conclusions are presented:

1- Wheel-track permanent deformation results for asphaltic wearing course mixes indicate that increasing of compaction temperature from 110 to 150 ºC will decrease the permanent deformation by 20.5 and 15.6 percent for coarse and fine gradation control asphalt mixtures respectively. While the rut depth (RD) decreases about 21.3 percent when the compaction temperature is increased from 110 to 150 ºC for coarse gradation SBS modified asphalt mixtures.

2- The permanent deformation is increased with the increases in asphalt content from optimum AC to opt. + 0.5 percent asphalt content for conventional and modified asphaltic mixtures. For (RD) value, it can be found that it increases about 10.6 percent when asphalt content increases from 4.6 to 5.1 percent for conventional coarse asphalt mixture , while it increased about 8 percent when asphalt content from 4.9 to 5.4 percent for SBS modified asphalt mixture

3- Wheel-track permanent deformation results showed effect of aggregate gradation of mixture on permanent deformation, it concluded that rutting resistance of asphalt paving mixes is affected by the mix gradation of aggregate. Coarser gradation had higher resistance to rutting from fine gradation of aggregate by 65.6 percent for conventional asphalt mixtures.

4- The permanent deformation decreases about 23.5 and 30.6 percent when the cement filler is used in asphaltic mixtures instead of limestone filler for coarse and fine gradation mixtures respectively. The effect of type of filler on the mixture rutting potential was more significant for the fine mixture than the coarse mixture.

5- The permanent displacement (RD) decrease about 37.22 and 29.5 percent when SBS polymer is used for coarse and fine gradation mixtures respectively. Based on the results, the use of asphalt modified by SBS polymers gives the coarse wearing course better rutting resistance than the fine gradation of the same asphalt performance grade.

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NOMENCLATURES

Term	Meaning
NCCLR	National Center for Construction Laboratories and Researches
NCHRP	Cooperative Highway Research Program
SBS	Styrene-Butadiene-Styrene
Superpave	Superior Performing Asphalt Pavement

Figure 1. A Plate shows Rutting Occurring in Pavements.

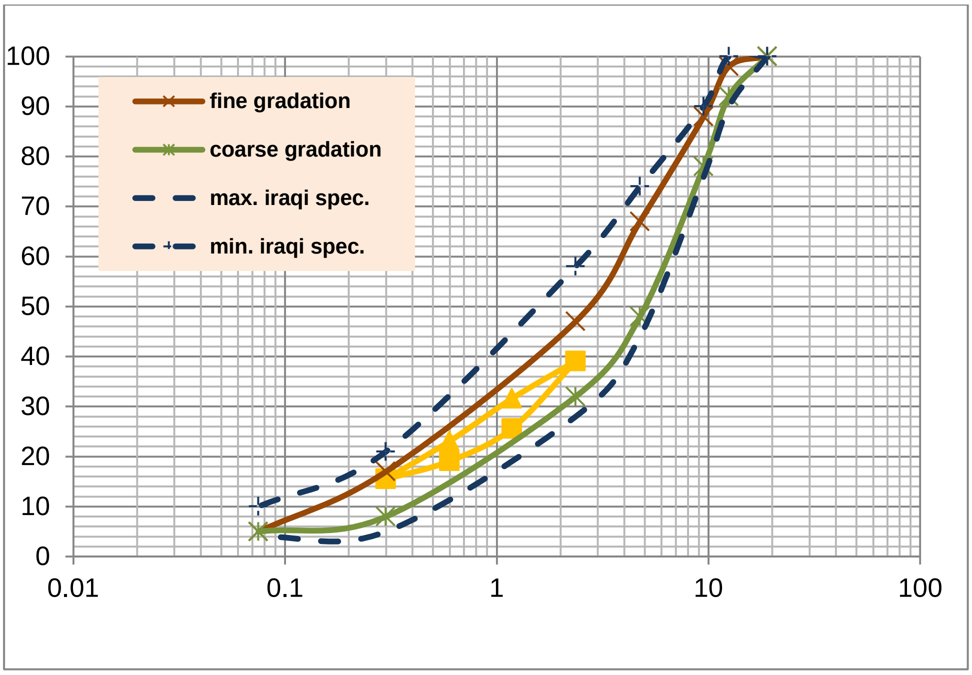

Figure 2. Selected Gradation for Aggregated Used.

Figure 3 . Preparation of Asphalt mixture.

Figure 4. Mixing of Asphalt Mixtures.

Figure 5. Asphaltic Slab before testing.

Figure 6. Wheel-Track device.

Figure 7. Slab under compaction effort.

Figure 8. Slab under loaded Wheel during testing.

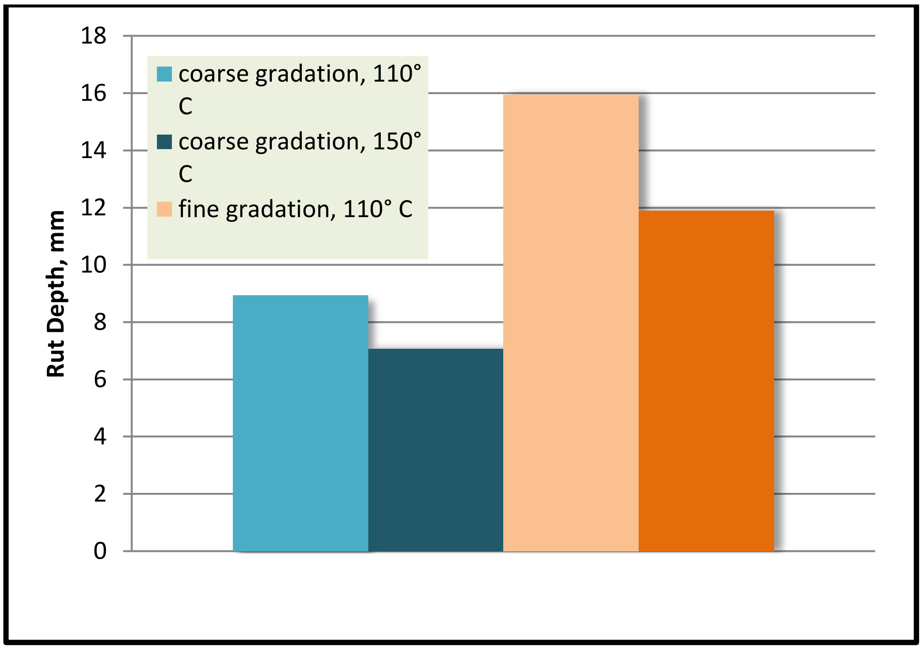

Figure 9. Effect of Compaction Temperature of control mixtures on Permanent Deformation.

Figure 10. Effect of Compaction Temperature on Permanent Deformation of Modified mixtures.

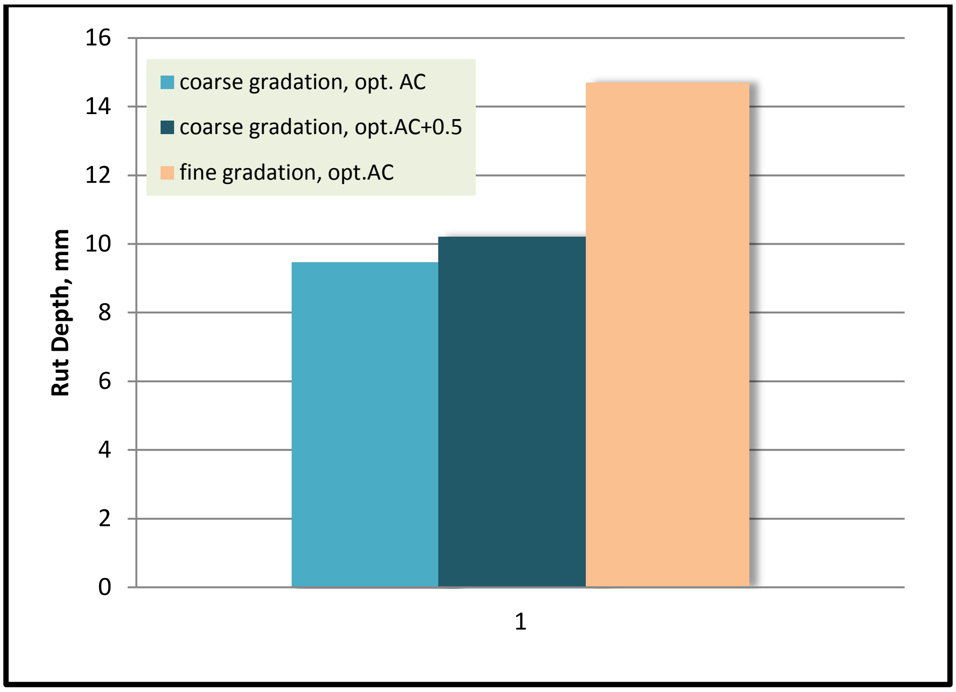

Figure 11. Effect of Asphalt content of conventional mixture on Permanent Deformation.

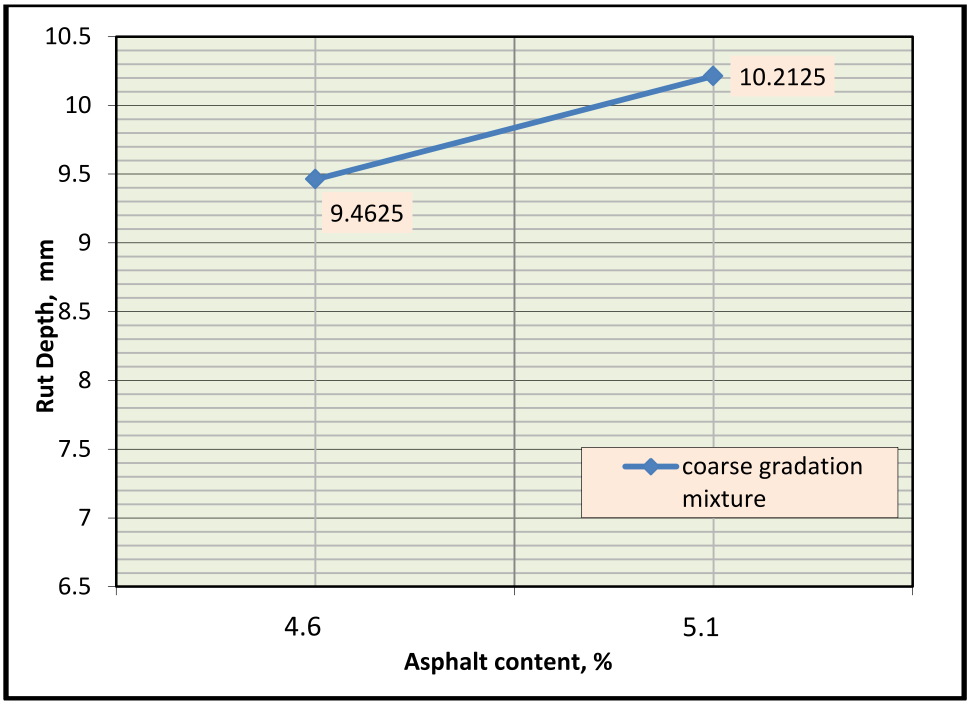

Figure 12. Change in Permanent Deformation with Asphalt content.

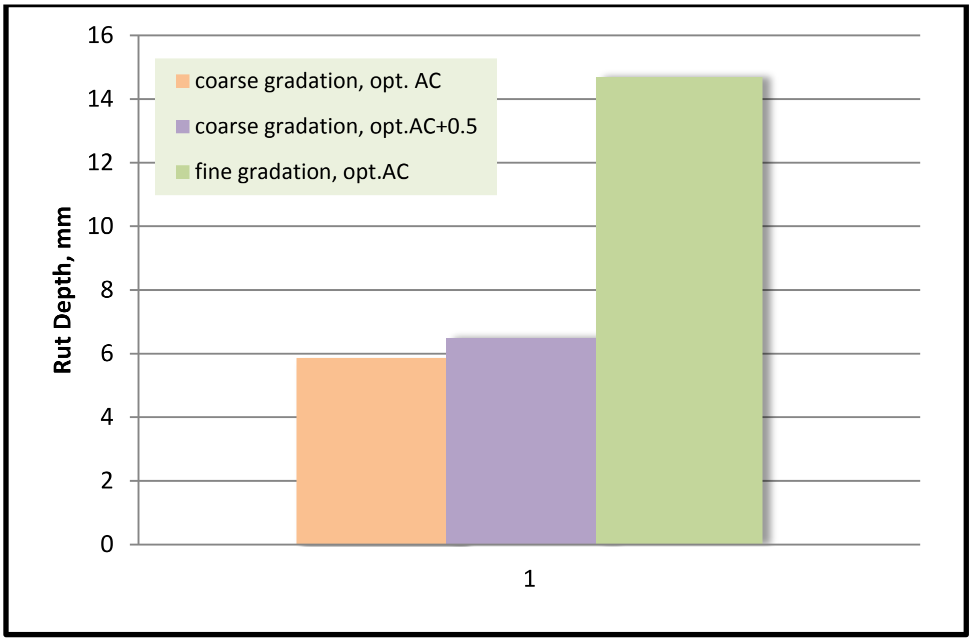

Figure 13. Effect of Asphalt content of modified mixture on Permanent Deformation.

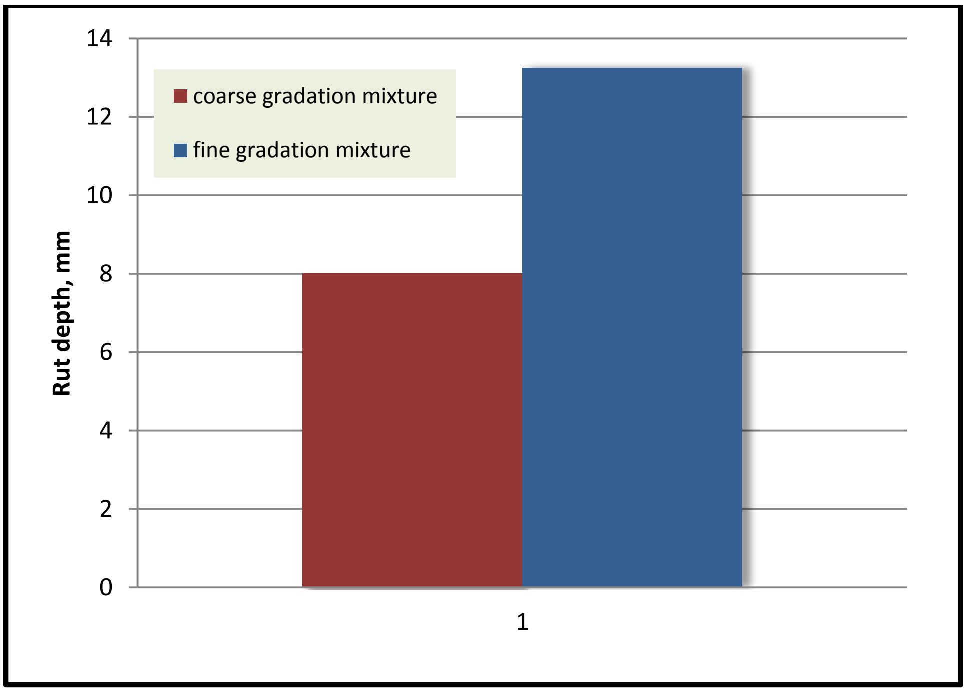

Figure 14. Effect of Aggregate Gradation of mixture on Permanent Deformation.

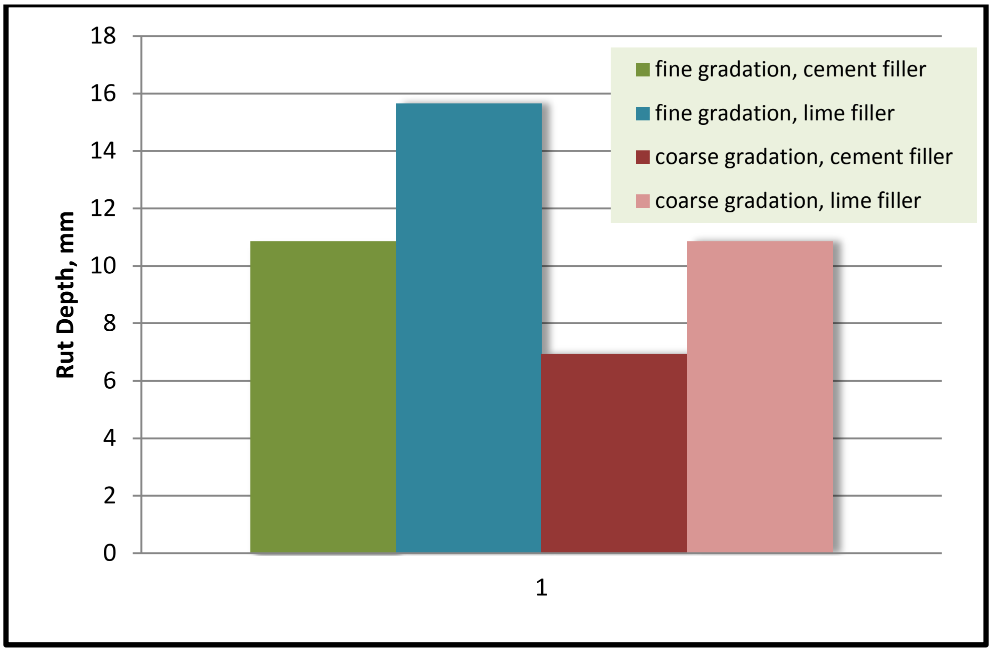

Figure 15. Effect of Type of Filler in mixture on Permanent Deformation.

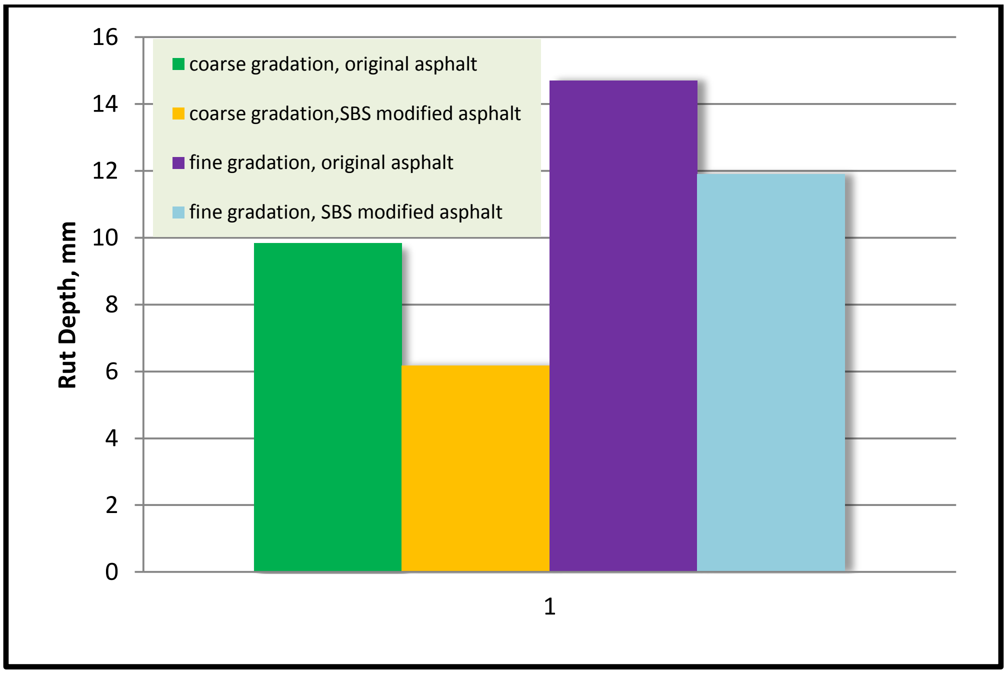

Figure 16. Effect of SBS Polymer on Permanent Deformation of mixtures.

Table 1. Properties of Asphalt Cement, according to ASTM Requirement and Iraqi Specifications.

Test	Test Conditions	ASTM Designation	Units	Penetration grade 40-50	
				Test results	SCRB specification
Penetration	100 gm, 25°C, 5 sec., (0.1mm)	D-5	1/10 mm	45	40-50
Rotational Viscometer,	135 °C	D-4402	Pas.sec.	0.52	……
	165 °C			0.13	
Ductility	25°C, 5 cm/min	D-113	cm	>100	>100
Flash Point	……	D-92	°C	289	Min.232
Specific Gravity	25°C	D-70	……	1.043	……
Softening Point	(4±1) °C/min.	D-36	°C	49	……
Residue from thin film oven test, D-1754					
%Retained penetration, of original	(25 °C , 100 gm , 5 sec)	D-5	1/10 mm	67.4	>55%
Mass loss	163 °C, 50gm, 5 hr	D-1754	%	0.38	< 0.75
Ductility of Residue	25 °C , 5 cm/min	D-113	cm	>100	> 25

Table 2. Percentage of Change in Permanent Deformation with Compaction Temperature.

Rut Depth , mm	Effect of Temperature, 110° to 150 °C (%)	
	Coarse gradation	Fine gradation
Control asphalt Mixtures	-20.5	-15.6
Modified asphalt Mixtures	-21.3	-

Table 3. Percentage of Change in Permanent Deformation with Original Asphalt Content.

Variable	Effect of Asphalt Content	
	4.6 % to 5.1 %	4.9 % to 5.4 %
	Original Asphalt Content	Modified Asphalt Content
Rut Depth , mm	10.6	8.0

Table 4. The Change in Permanent Deformation with Type of Filler.

Rut Depth , mm	Effect of Type of Filler , %
	From (lime) to (cement)
Coarse gradation	-23.5
Fine gradation	-30.6

Table 5. Percentage of Change in Permanent Deformation with Polymers Content.

Variable	Effect of Polymer (SBS) Content (%)	
	Coarse gradation	Fine gradation
Rut Depth , mm	-37.22	-29.5