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Effect of Aggregate Gradation and Filler Content on the Rutting Resistance of Modified Colored Hot Mix Asphalt

Samer A. Naji[1], Alaa H. Abed [2*]

Authors affiliations:
1) Civil Eng. Dept., Al-Nahrain University, Baghdad-Iraq.
SamirSamer799@gmail.com

2*) Civil Eng. Dept., Al-Nahrain University, Baghdad-Iraq.
Alaa.abed@eng.nahrainuniv.edu.iq

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Abstract

Rutting is considered as the most generated distress in Iraqi roads as a result of the high temperature and excessive traffic load. So, it is essential to utilize polymer modified binder to increase the performance of pavements. The objective of this paper is to assess the effect of aggregate gradation and filler content on the rutting formation of Colored Hot Mix Asphalt CHMA. The HMA was colored by using iron oxide as filler to produce red HMA. Two blends were used: fine and coarse with two different types of filler iron oxide for CHMA and limestone for conventional HMA with two filler content 6% and 10%. Neat (AC 40-50) and modified asphalt (AC 40-50 + 4%SBS) were used. Tests are held on adding 4% Styrene Butadiene Styrene (SBS) by the weight of neat asphalt (AC 40-50) to raise the performance grade by two grades from PG (64-16) to PG (76-16) [1] and [2]. The wheel tracking test is used to assess the rut depth of the CHMA. The test results showed that the using iron oxide with neat asphalt increase the rut depth resistance by 200 and 400 failure load cycles than mixtures using limestone (cycles that mix reach 25 mm rut depth) for fine and coarse mix respectively. Also, the effect of gradation shows that the fine mixture fails at 4000 cycles while the coarse mixture fails at 1800 cycles for 6% limestone mixtures. Increasing the iron oxide content from 6% to 10% leads to increase the failure load cycles by 2200 and 1200 cycles for fine and coarse mixture respectively using modified asphalt. The fine mixture with 10% iron oxide using modified asphalt gives the best performance with 7000 cycles than the coarse mixture with 10% filler content and modified asphalt with 4000 cycles. irrespective the filler and type of binder, the dense mixtures using iron oxide as filler exhibit better resistance to rutting formation than coarse mixtures.

Keywords: colored pavement, rutting, modified binder

تاثير تدرج الركام ومحتوى المادة المالئة على مقاومة تكوين التخدد للخلطات الاسفلتية الحارة المحسنة الملونة

سامر علي ناجي ، علاء حسين عبد

الخلاصة:

يعتبر التخدد من اكثرانواع الفشل التي تحدث في الطرق العراقية نتيجة ارتفاع درجة الحرارة والحمل المروري الزائد. لذلك ، من الضروري استخدام مادة رابطة معدلة بالبوليمر لزيادة أداء الطرق. الهدف من هذا البحث هو تقييم تأثير تدرج الركام ومحتوى المادة المالئة على تكوين الاخاديد للخلطات الاسفلتية الملونة CHMA. تم تلوين HMA باستخدام أكسيد الحديد الثلاثي كمادة مالئة لانتاج HMA باللون الاحمر. تم استخدام خليطين ناعم وخشن مع نوعين مختلفين من المواد المالئة : أكسيد الحديد الثلاثي ل CHMA و الحجر الجيري ل HMA التقليدية مع محتوى مادة مالئة6% و 10% . تم استخدام اسفلت خام (AC 40-50) و اسفلت معدل (AC 40-50 +4% SBS). تم استخدام 4% SBS بالاعتماد على بحوث سابقة [1] و [2] لرفع درجة اداء الاسفلت درجتين من (64-16) الى (76-16). استخدم Wheel tracking test لتقييم عمق التخدد للCHMA واظهرت نتائج ان استخدام اوكسيد الحديد مع الاسفلت الخام يرفع من مقاومة التخدد

الى بمقدار 200 و400 دورة تحميل عند الفشل (عدد الدوات التي عندها يصل عمق التخدد الى 25 ملم) للخلطة الناعمة والخشنة على التوالي.كذلك تاثير التدرج يبين ان الخلطة الناعمة تفشل عند 4000 دورة بينما الخلطة الخشنة تفشل عند 1800 دورة عند استخدام 6% من الحجر الجيري كمادة مالئة. زيادة محتوى اوكسيد الحديد من 6% الى 10% يؤدي الى زيادة عدد دورات الفشل بمقدار 2200 و 1200 دورة للخلطة الناعمة والخشنة على التوالي باستخدام اسفلت معدل. الخلطة الناعمة مع 10% اوكسيد حديد و اسفلت معدل تعطي افضل اداء ب 7000 دورة بينما الخلطة الخشنة تكون عند 4000 دورة عند 10% اوكسيد حديد واسفلت معدل. بغض النظر عن نوع المادة المالئة والاسفلت المستخدم فان الخلطات الكثيفة التي تستخدم الاوكسيد الحديد كمادة مالئة بغض النظر عن كمية المادة ونوع المادة اللاصقة تظهر مقاومة افضل لتكوين الاخاديد من الخلطات الخشنة.

1. Introduction

High temperature distress known as rutting are the most pavement failure occurred in the Iraqi roads. As the asphalt is considered as viscoelastic material which it is viscos liquid at high temperature and elastic solid at low temperature. Consequently, it is essential to improve the performance grade of asphalt by adding modifiers when added to the native bitumen, alters its chemical structure and physical and/or mechanical properties. The widely used modifiers added to native binder is the elastomer Styrene-Butadiene-Styrene (SBS) which is readily available at reasonable cost [3].

Also, using 4.7% SBS improves the rutting resistance at high pavement temperature this is because of using sbs leads to increase the viscosity and softening point of binder hence the binder stiffness ($G^*/\sin\delta$) is increased [4].

(Habeeb et al, 2011) selected a coarse and fine gradation mix to be test, the results showed that rut depth for coarse gradation was 62% more than that of fine gradation at 10,000 cycles for the same binder type and content. The mixture with fine gradations have higher strength. This is a result of the higher density and stability of the fine mix [5].

(Alamdary et al., 2020) prepared laboratory mixture samples to evaluate permanent deformation. The samples were compacted at a targeted 7 percent air voids content and tested using the Asphalt Pavement Analyzer (APA) at 58°C. Two samples were prepared. One sample with 7% iron oxide and the other with used 7% limestone as filler. Both samples were prepared with the same asphalt type PG70-34. After 8000 cycles the rut depth was 2.9 mm for the red sample while it was 3.3 mm for the black one [6].

(Guiffre et al., 2018) studied the rheological properties of colored hot mix asphalt. The test results of softening point and stiffness showed that addition of iron oxide to the modified asphalt can increase the softening point by 23.7% and increase the complex modulus by 250% as compared with conventional HMA. Hence, the modified asphalt with iron oxide produce more resistance to permanent deformation [7].

(Varamini, 2016) prepared colored hot mix asphalt (CHMA) samples which consist of a pink granite aggregate blend, red pigment(iron oxide) and polymer modified PG 70-28 asphalt binder. Hamburg Wheel Tracking test was used to determine the resistance of CHMA to permanent deformation as compared to conventional mix. The test result showed that the polymer modified CHMA generate small rut depth after 10,000 cycles of 2.31 mm for PG 58-28 while for CHMA with PG 70-28 the test was extended to 30,000 cycles [8].

2. Materials

2.1 Asphalt cement

Neat bitumen (AC 40-50) brought from al Doura refinery was used. The physical properties according to ASTM requirement and State Corporation for Roads and Bridges (SCRB, R9) [9] are shown in Table (1) [10] to [16].

2.2 Modified Asphalt cement

One type of polymer is used in this research called Styrene Butadiene Styrene (SBS). 4% by the weight of neat asphalt (AC 40-50) is added to produce a modified binder that raise the performance grade two grades of (AC 40-50) from (64-16) to (76-16). The SBS material is shown in Figure (1). The physical properties according to ASTM and SCRB are shown in Table (2).

Figure (1): Photograph of SBS Polymer

2.3 Aggregate

The used aggregates in laboratory work is crushed quartz from Al-Nibaie quarry which is commonly used for asphalt mixes in Baghdad city. Chemical composition and Physical properties of used aggregate are shown in Tables (3) and (4) [17] to [23].

Table (1): Properties of Asphalt Cement, according to ASTM Requirement and Iraqi specifications

Test	ASTM Designation	Units	Penetration Grade 40/50	
			Test Results	SCRB Specification
penetration	D-5	1/10 mm	44	40-50
Rotational viscometer	D-4402	Pas.sec	0.56 @135°C	……
			0.19 @165°C	
ductility	D-113	cm	>100	>100
Flash point	D-92	°C	275	Min.232
Specific gravity	D-70	…	1.049	……
Softening point	D-36	°C	51	……
Residue from thin film oven test, D-1754				
% Retained penetration of original	D-5	1/10 mm	67.4	> 55%

Mass loss	D-1754	%	0.38	<0.75
Ductility of residue	D-113	cm	45	>25

Table (2): Properties of modified Asphalt Cement, according to ASTM Requirement and Iraqi specifications

Test	ASTM Designation	Units	Original 40-50	Modified with 4% SBS	SCRB Spec.
penetration	D-5	1/10 mm	44	27	40-50
Rotational viscometer	D-4402	Pas.sec	0.56 @135°C	1.67 @135°C	……
			0.19 @165°C	0.41 @165°C	
ductility	D-113	cm	>100		>100
Flash point	D-92	°C	275	265	Min.232
Specific gravity	D-70	…	1.049	1.01	……
Softening point	D-36	°C	51	62	……
Residue from the oven test D-1754					
% Retained penetration of original	D-5	1/10 mm	67.4		> 55%
Mass loss	D-1754	%	0.38		<0.75
Ductility of residue	D-113	cm	45		>25

Table (3): Chemical Composition of Al-Nibaee (National Center for Construction Laboratories and Researches)

Chemical compound	Content%
Silica, SiO_2	84.73
Lime, CaO	3.37
Magnwasia, MgO	0.53
Sulphuric Anhydride, SO	2.9
Alumina, AlO	0.62
Ferric Oxide, FeO	0.58
Loss on Ignition	6.25
Total	98.98
Mineral Composition	
Quartz	81.2
Calcite	10.02

Table (4): Physical Properties of Al-Nibaie Aggregate

No	Laboratory test	Designation	Test Results	SCRB Limits
1	coarse aggregate % fractured particles (Angularity %)	ASTM D-5821	97	90 Min
2	Fine aggregate angularity, %	T-304	61	45 Min.
3	Percent flat and elongated Particles, %	ASTM D-4791	1.6	10 Max.
4	Clay content by Sand equivalent, %	T-176	51	45 Min.
5	Toughness, by (Los Angeles abrasion),	T-96	15.28	30 Max.
6	Soundness loss by sodium sulfate solution, %	T-104	2.46	12 Max.
7	Deleterious materials, %	T-112	0.5	3 Max.

2.4 Filler

The filler used in this work are limestone dust brought from the lime factory in Karbala' governorate, and a synthetic red pigment known as metal oxide (α-Fe_2O_3) which is inorganic substance obtained from Hamurabi asphalt factory. Figure (2) shows the filler types (Iron oxide III and limestone) used in this research. The physical properties of the used lime filler is presented in Tables (5) while the physical and chemical properties of red pigment are presented in Table (6)

Figure (2): filler type used in this search left: Iron oxide III, right: limestone.

Table (5): Physical Properties of limestone Filler

Property	Test result
Specific gravity	2.73
%passing sieve No.200	98
Specific surface area	307.3

Table (6): physical and Chemical Properties of red pigment (https://byjus.com/chemistry/iron-oxide/)

Physical state	Solid, powder
color	Red brown
Density	5.24 g/cm3
Solubility	Insoluble in water, soluble in strong acid

3. Job mix formula

Marshall Mix design method was selected to produce two blend mixtures coarse and fine for the preparation of slabs. The job mix formula is selected within SCRB limits as shown in Figure (3). Two percentages of filler were used 6% and 10% for both limestone and iron oxide for each blend.

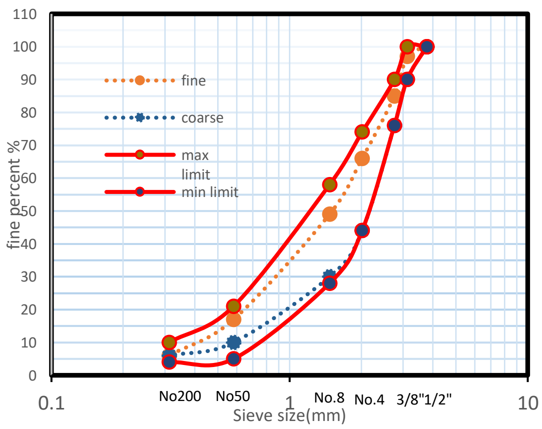


Figure (3): Design job mix formula with SCRB limits

4- Mixing and Compaction Temperature

According to (ASTM-D6927) [24], the mixing temperature is corresponding to viscosity of 0.17±0.02 while the compaction temperature is corresponding to viscosity of and 0.28±0.03 Pascal-seconds (Pa·s). The Rotational Viscometer (RV) has utilized to determine the viscosity of asphalt binder to ensure that the binder is sufficiently fluid (workable) at construction temperatures. As shown in Figure (4) Brookfield Rheometer which is frequently used to measure viscosity at two temperatures (135°C and 165°C). Based on Brookfield Rheometer test, the mixing temperature range was (160°C to 163°C) and the compaction temperature range was (152°C to 156°C) for the used asphalt binder as shown in Figure (5).

Figure (4): Viscosity test of binder by Brookfield rheometer

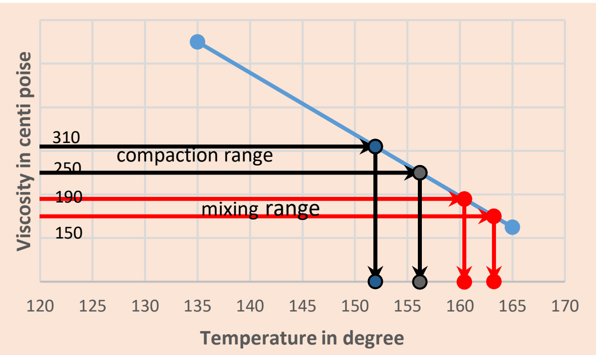


Figure (5): Relation between the number of blows and air void percentage

5. Slabs Preparation

Eight slabs are prepared, four slabs for fine blend and other four for coarse blend. the mixture was short time aged in oven according to (AASHTO R 30) [25] and compacted in slab compactor device as shown in Figure (6) according to (EN12697-33) [26]. The slab was prepared according to the job mix formula with slab dimension of (400*305*50 mm) after compaction.

Figure (6): Roller Compactor Device

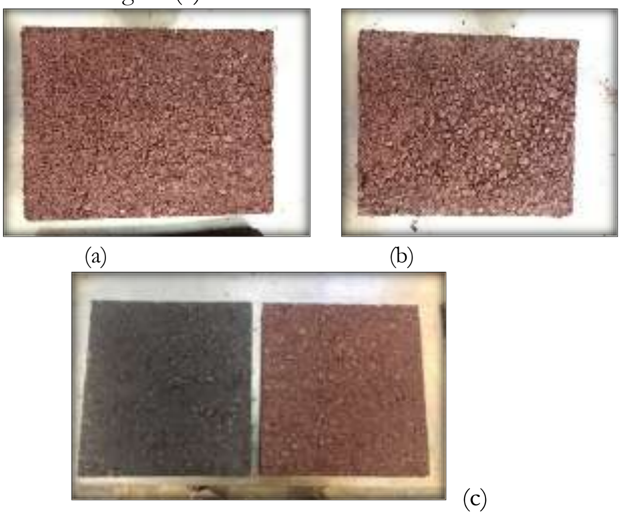
Figure (7) shows the prepared colored hot mix asphalt slabs with conventional mix at different gradations and filler content. The optimum asphalt content for prepared slabs are shown in Table (7).

Table (7): Optimum binder content for each prepared slab

Mix type	Optimum binder content %
Fine mix using 6% limestone dust with neat asphalt	5.6
Fine mix using 6% iron oxide with neat asphalt	5.4
Fine mix using 6% iron oxide with modified asphalt	5.5
Fine mix using 10% iron oxide with modified asphalt	5.6
Coarse mix using 6% limestone dust with neat asphalt	4.9
Coarse mix using 6% iron oxide with neat asphalt	4.8
Coarse mix using 6% iron oxide with modified asphalt	4.9
Coarse mix using 10% iron oxide with modified asphalt	5.1

6- Evaluation of Permanent Deformation by Wheel Tracking Test.

After the preparation of slabs is completed. The slabs are ready to be tested by wheel tracking device in accordance with EN12697-22. The wheel tracking device consist of closed chamber under temperature control of 60°C and 45mm wheel thickness which apply a 70 kg load that represent an Equivalent Single Axle Load (ESAL) of 80 KN. The rut depth was measured each 100 cycle by a fixed Linear Value Displacement Transducer (LVDT) connected to data logger device to obtain a micro millimeter readings as shown in Figure (8).



(a) (b) (c)

Figure (7): (a) fine mix with 10% Iron oxide III (b) coarse mix with 6% oxide III (c) fine mix: left with 6% limestone Right: with 6% Iron oxide III

Figure (8): left: wheel tracking device with LVDT, right: data logger

The test is accomplished when a rut depth reaches 25 mm or 10,000 load cycles completed whichever is smaller.

The readings of rut depth in millimeters versus load cycles in numbers are plotted in Excell data sheet. the rut depth versus number of cycles for fine and coarse mixtures are shown in Figure (9) and (10) respectively.

Figures 9 and 10 show the effect of aggregate gradation, filler type and content and binder type on the resistance to rut formation

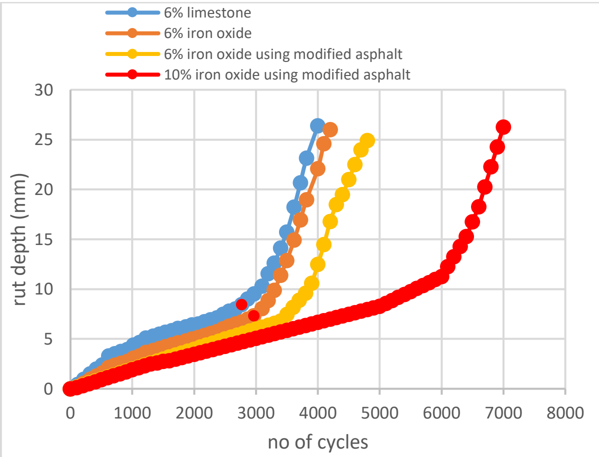


Figure (9): Rut Depth versus Number of Cycles for Fine Mix using various Filler and Binder Types

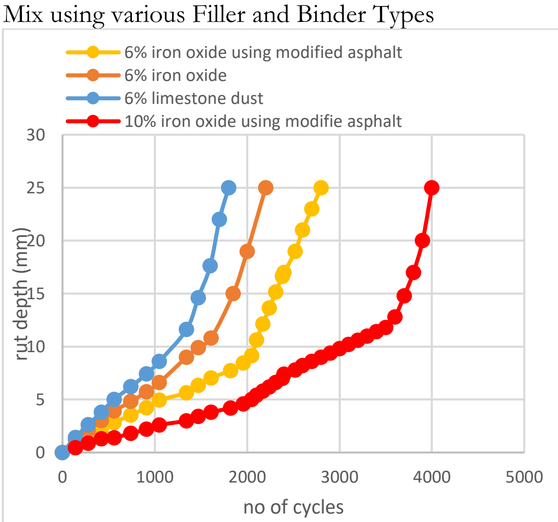


Figure (10): Rut Depth versus Number of Cycles for Coarse Mix using various Filler and Binder Types

7. Effect of Aggregate Gradation on the Plastic Deformation Resistance

It can be concluded that the dense mixture had better resistance to plastic deformation where the fine mixture fails at 4000 cycles while the coarse mixture fails at 1800 cycles for 6% limestone dust. The better performance of fine mixture than the coarse one is belonged to the better particles packing between the aggregate particles that densify the mix and make it more resisting to tire pressure under high temperature, and this is complied with the high stability of dense mixtures than the coarse one. The mechanism of load transferring under the tire differs between the coarse and fine mixtures. The coarse aggregate under tire try to run away by pushing the binder around it and as the fine aggregates are low, the coarse aggregates suddenly slides. In opposite to the fine mixtures where the particles are packed together taking long time to be displaced (shear plane formation) as a result of high densification.

8. Effect of the Asphalt Mastic Type on the Plastic Deformation Resistance

8.1 Effect of filler type

Two different types of filler are used to check the improvement in resisting the plastic deformation of HMA slabs for the same binder type. From Figures (9) and (10), it can be distinguished that the mixture using iron oxide as filler has better resistance to plastic deformation than mixtures using limestone dust. Enhancement about 5% and 23% in number of cycles at failure is observed in fine and coarse mixtures respectively at 6% filler content. This development related directly to the high stiffness of asphalt mastic which gained its strength from the active reaction between iron oxide and asphalt forming high cohesional mastic that keep the mix components firmly integrated together. Hence more resistance to plastic deformation is maintained.

8.2 Effect of binder type and filler content increment

Two different types of binder are used: neat and modified asphalt to check the improvement in resisting the plastic deformation of HMA slabs with increasing the filler content. From Figure (9), the fine mix using modified asphalt with 6% iron oxide as filler can enhance the resisting to rut formation to significant extent about 700 cycles at failure more than the same mixture using neat asphalt. Also it can be observed that increasing the iron oxide content from 6% to 10% using modified asphalt leads to raise up the cycles at failure by 2200 cycles (from 4800 to 7000 cycles at failure).

On the other hand, from Figure (10), it can be concluded that coarse mix using modified asphalt for mixtures with 6% iron oxide as filler can improve the resisting to rut formation to about 600 cycles at failure more than the same mixture using neat asphalt. Also, increasing the iron oxide content from 6% to 10% using modified asphalt leads to raise up the cycles at failure by 1200 cycles (from 2800 to 4000 cycles at failure). The interruption of this noticeable melioration is mainly related to the high viscosity of asphalt mastic where the viscosity of binder is increased effectively when the iron oxide is used with asphalt modified by SBS polymer in the formation of HMA. This viscosity is the major reason for the stiffness of HMA and consider the main factor to resist the high temperature asphalt concrete failure under traffic load.

9. Conclusion

1-The wheel track test results show a clear indication about the effect of aggregate gradation and type of filler using in colored hot mix asphalt where the dense mixture exhibit a better resistance for rutting formation than the coarse mixtures.

2- Using modified asphalt with iron oxide for fine and coarse blends can increase the load cycles at failure

about 700 and 600 cycles respectively than mixture with 6% limestone dust using neat asphalt.
3- Increasing the iron oxide content from 6% to 10% for fine and coarse blends using modified asphalt can increase the load cycles at failure by 2200 and 1200 cycles respectively.
4- The dense mixtures show better performance against the rut formation due to the high compatible particles structure that is made by the better particles packing under compaction (better shear strength against the shear deformation that forming rutting) which make the aggregates interlock together as one mass. Moreover, the high stiffness of asphalt mastic as a result of better mastic cohesion which strengthen the bonding between aggregate particles. Hence, more shear strength is maintained. Consequently, better resistance to rutting is gained.

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