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Influence of using ordinary Portland cement and hydrated lime as mineral filler on the characteristics of asphalt mix

M. S. Eisa [1*], E. A. El-Kasaby [2], M. M. Azzam [3]

[1]Civil Engineering Department, Benha Faculty of Engineering, Benha University, P.O. 13512, New Benha, Qalubiya Governorate, Benha, Egypt
E-mail: mohamedeisa524@bhit.bu.edu.eg
ORCID: 0000-0002-4111-1829

[2]Professor, Civil Engineering Department, Benha Faculty of Engineering, Benha University, Benha, Egypt
E-mail: elsayed.elkasaby@bhit.bu.edu.eg

[3]MSc. candidate, Benha Faculty of Engineering, Benha University, Benha, Egypt
E-mail: mohamed.mamdouh504@yahoo.com

الملخص العربى :

تواجه العديد من الدول الكثير من التحديات في تحسين وصيانة الخلطات الاسفلتية المتدهورة. غالبا ما يظهر في الرصف المرن عيوب مثل الشروخ والتخدد خصوصا في المناطق الحارة. ازداد استخدام الاضافات في الخلطات الاسفلتية لان معظم الدول في الفترة الاخيرة اتجهت الى طرق تحسين اقتصادية للحصول على افضل النتائج للخلطات الاسفلتية الساخنة. تقدم هذه الدراسة تقييم عملي لتأثير انواع مختلفة من البودرة على خصائص الخلطات الاسفلتية باستخدام نوعين من الاضافات وهما الاسمنت البورتلاندي العادي والجير المطفي. البودرة الجيرية استخدمت كبودرة مرجعية. بعد ذلك تم تحضير 9 عينات من الخلطات الاسفلتية الساخنة باستخدام طريقة مارشال. تم اجراء اختبار الثبات والانسياب على العينات. تم حساب قيم الثبات والانسياب. تم حساب معاملات مارشال بالنسبة لمحتوى الاسفلت الامثل ونسب الاضافات. بعد ذلك تم اجراء اختبارات الاداء لتقييم خصائص الخطات الاسفلتية الساخنة، تتضمن هذه الاختبارات اختبار الفقد في الثبات والعجلة الترددية والشد الغير مباشر. ادت النتائج الى استنتاجات ملحوظة في استخدام الاسمنت البورتلاندي العادي والجير المطفي في تحسين خصائص الخلطات الاسفلتية الساخنة. توصي هذه الدراسة باستخدام خليط مناسب يحتوي على بودرة مكونة من 50% بالوزن من بودرة الاسمنت البوتلاندي العادي او 100% من بودرة الجير المطفي.

Abstract:

Many countries are facing many challenges in strengthening and maintaining the deteriorated asphalt mixes. The flexible pavement often shows distresses such as cracks and rutting in hot regions. The utilization of additives on asphalt mixes has increased in recent years because most countries are turning to the cheapest improvements and the best results for hot mix asphalt (HMA) mixtures. This study presents an experimental evaluation in the influences of various fillers on the characteristics of HMA mixes, using two types of additives, namely ordinary Portland cement (OPC) and hydrated lime (HL). Limestone dust (LD) was taken as a reference filler. After that, 9 HMA samples were prepared by using the method of Marshall mix design. Tests of stability and flow were conducted to the samples. Then the values of stability and flow were calculated. For the optimum asphalt content (OAC) and additive percentages, the parameters of Marshall were determined. After that, the tests of performance were conducted to evaluate the characteristics of HMA mixes, including stability loss, wheel tracking and indirect tensile strength tests. The results led to remarkable findings considering the utilization of ordinary Portland cement (OPC) and hydrated lime (HL) to enhance the characteristics of HMA mixes. This study recommends a suitable mixture with filler included 100 wt.% OPC or 50 wt.% HL respectively.

Keywords: Mineral filler; ordinary Portland cement (OPC); hydrated lime (HL); Marshal stability; wheel tracking

1. Introduction

The continuous traffic growth requires, with an increase in axle loads, the enhancement of the materials of highway paving is required. Researchers aim to provide safe, durable, economical, and able to resist the expected loads on it [1]. The flexible pavement displays distresses such as rutting and cracks in hot regions. To attain this aim, researchers are devoted to choosing the paving materials which decrease the distresses of pavement and improve asphalt pavement performance. Filler provides an important function in investigating the characteristics of the mix, particularly its aggregate interlocking influences [1]. At present, in hot regions, the ordinary asphalt viscosity 60/70 (AC 60/70) has many disadvantages, where road surface temperature can reach 70 °C.

This study displays the utilization of OPC as a filler alternative to enhance the hardness of asphalt mixtures made from B 60/70 bitumen. This modified mix improves pavement stability and resistance to high temperature. To quantify the influences of OPC on asphalt mixtures performance in hot regions, four different proportions of OPC (25%, 50%, 75% and 100%) are used as filler alternatives in three different blends. This study indicated that the OPC filler redisplayed a more stable alternative to ordinary asphalt which also decreases thickness requirements, due to the resulting higher stiffness modulus of rigidity [2].

HL has been used as an additive for HMA mixtures from their beginning. It experienced a strong interest when frost and damage of moisture became some of the most pavement failure patterns with time. HL has been known to be more than a damage of moisture additive; it decreases chemical aging of the asphalt and stiffens the mastic more than conventional filler. HL improves the surface characteristics of aggregate, allowing for the development of surface composition and roughness more favorable to asphalt adhesion. HL treats the existing clayey particles adhering to the aggregate surface, inhibiting their detrimental influence on the mix. In addition, HL can react chemically with asphalt acids, which in turn slows down the age-hardening kinetics and neutralizes the influence of the "bad" adhesion promoters originally present inside the asphalt, improving mix moisture resistance [3].

In this study, and in view of the aforementioned, and to attain the goal of enhancement in asphalt mixes, these additives were used in different proportions, as cement and lime were used as fillers and in different proportions. Attention has been paid to these enhancements for their economic feasibility in addition to their impact that was demonstrated by conducting some laboratory tests that proved that these tests are superior to those materials.

2. Aims

The main aims of this study are to examine the influences of the quantity and quality of mineral filler (ordinary Portland cement, and hydrated lime) on the characteristics and performance of HMA mixtures and calculate the optimum additive filler percentage to obtain the desired stability and flow values.

3. Methodology

Ten tests were performed on the chosen materials to check their validity: five tests were performed on aggregates and five tests were performed on asphalt. After that, the OAC was calculated and remained the same for all mixtures. Limestone dust (LD) was taken as a reference filler. After that, it was substituted to some percentage by ordinary Portland cement (OPC) and hydrated lime (HL). Tests of stability and flow were conducted to samples. Values of stability and flow were reported. Based on these values, the optimum percentage of OPC and HL was identified. In addition, all prepared samples characteristics were compared with those of a reference mix. Finally, tests of performance were performed on the mixtures with optimum additive filler percentage, including stability loss, wheel tracking and indirect tensile strength tests.

4. Materials

Tested HMA mixtures were consisted of aggregates, asphalt and mineral filler. All materials testing were performed in accordance with AASHTO.

4.1. Aggregates

Crushed dolomite stone was used as coarse aggregates portion in HMA mixes. Siliceous sand was used as fine aggregates of the prepared HMA mixtures. Table 1 displays the design gradation of aggregates and specification limits in accordance with the Egyptian code [4]. Table 2 displays aggregates characteristics in accordance with the Egyptian specification of asphalt mixtures [4]

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Table 1 Characteristics of aggregates used

Test		Results	Specification limits
Los Angles abrasion (%)	After 100 revolution	5%	≤ 10%
	After washing after 500 revolution	26%	≤ 40%
Water absorption (%)		2.5%	≤ 5%
Bulk specific gravity (g/cm^3)		2.66 g/cm^3	--

Table 2 Aggregates design gradation

Sieve size (mm)	Design gradation	Specification limits
25	100	100
19	96.9	80-100
12.5	83.2	--
9.5	74.2	60-80
4.75	48.6	48-65
2.36	37.3	35-50
1.18	32.6	--
0.6	23.9	19-30
0.3	17.3	13-23
0.15	11.1	7-15
0.075	7.5	3-8

4.2. Asphalt

Suez asphalt cement was used to prepare all HMA mixes. Table 3 displays asphalt characteristics.

Table 3 Characteristics of asphalt used

Test	Results	Specification limits
Penetration (0.1 mm)	64	60-70
Softening point (ºc)	48	45-55
Flash point (ºc)	+270	+250
Kinematic viscosity (cst)	428	+320
Ductility (cm)	+100	≥ 95

4.3. Mineral filler

The mineral filler used in the prepared mixtures was limestone dust (LD). Table 4 displays the design gradation of the three types of fillers. Fig. 1 displays the appearance of the three types of fillers.

Table 4 Mineral filler gradation

Sieve size (mm)	Design gradation			Specification limits
	LD	OPC	HL	
0.6	100	100	100	100%
0.3	100	100	100	--
0.15	95	98	91.3	> 85%
0.075	87	97	85.7	> 65%

Fig. 1 The appearance of the two types of fillers: (a) Limestone dust; (b) Ordinary Portland cement; (c) Hydrated lime

To investigate the influence of utilization different additives as a mineral filler on asphalt mixes characteristics, 9 HMA mixtures were prepared. The first HMA mixture composes of the chosen materials, the OAC (5.2%) and 5% LD as reference filler, being named the (Reference Mix.). After that, four HMA mixtures with the chosen materials, the OAC (5.2%) and different percentages of OPC (25, 50, 75, 100%) were prepared, and the method of Marshall mix design was performed to calculate the optimum ordinary Portland cement content (O.OPC.C), resulting in the first comparison mixture (Comp. Mix. 1). After that, four HMA mixtures with the chosen materials, the OAC (5.2%) and percentages of HL (25, 50, 75, 100%) were prepared, and the method of Marshall mix design was performed to calculate the optimum hydrated lime content (O.HL.C), resulting in the second comparison mixture (Comp. Mix. 2). After that, these three main mixtures were applied to the performance tests to investigate the behavior of HMA mixtures with OPC or HL as additive. These 9 HMA mixtures were displayed in table 5.

Table 5 The 9 HMA mixtures

Filler type	Code	Description	Function	Objective
LD	Mix 0	OAC % + 100% LD	Calculate stability & flow	Reference Mix
OPC	Mix 1	OAC % + 25% OPC + 75% LD	Calculate O.OPC.C of comparison mixes	Comp. Mix. 1
	Mix 2	OAC % + 50% OPC + 50% LD		
	Mix 3	OAC % + 75% OPC + 25% LD		
	Mix 4	OAC % + 100% OPC + 0.0% LD		
HL	Mix 5	OAC % + 25% HL + 75% LD	Calculate O.HL.C of comparison mixes	Comp. Mix. 2
	Mix 6	OAC % + 50% HL + 50% LD		
	Mix 7	OAC % + 75% HL + 25% LD		
	Mix 8	OAC % + 100% HL + 0.0% LD		

5. Experimental works and results

5.1. Optimum asphalt content (OAC)

Four HMA mixes with the chosen materials in the previous phase, asphalt contents (4.5, 5.0, 5.5, 6.0%) and 5% LD as reference filler were prepared. The method of Marshall mix design was performed for the wearing surface mixture (Mix 4C) to evaluate mixes characteristics in accordance with AASHTO T-166 [5]. These four HMA mixtures were applied to the Marshall test to get the values of stability and flow. The OAC was calculated, resulting in a value of 5.2% to exhibit peak stability and desired flow, actual specific gravity, and reasonable ratio of air voids. Table 6 displays OAC mix characteristics with 5% LD as reference filler.

Table 6 Marshall characteristics at optimum asphalt percentage (OAC)

Characteristics	Results	Specification limits
Stability (kg)	1300	> 900 kg
Flow (mm)	3.6	2-4 mm
Stiffness (kg/mm)	361	300-500 kg/mm
Specific Gravity (g/cm^3)	2.357	--
% Air voids (V_a)	3.62	3-5 %
% Voids in Mineral Aggregate (VMA)	14.65	--
% Voids Filled with Asphalt (VFA)	75.3	--

5.2.Optimum ordinary Portland cement content (O.OPC.C)

Four HMA mixes with the chosen materials, the OAC (5.2%), and percentages of OPC (25, 50, 75, 100%) were prepared. The method of Marshall mix design was performed to calculate the optimum ordinary Portland cement content (O.OPC.C), resulting in a value of 100%. Table 7 displays the results of Marshall test for the percentages of OPC, whereas table 8 displays O.OPC.C mix characteristics.

Table 7 Characteristics of ordinary Portland cement mixes

Characteristics \ Mix. no.	M1	M2	M3	M4
Stability (kg)	1368	1413	1476	1545
Flow (mm)	3.5	3.4	3.2	3.1
Stiffness (kg/mm)	391	416	461	498
Specific gravity (g/cm^3)	2.367	2.377	2.381	2.395
% V_a	3.58	3.52	3.43	3.28
% VMA	14.33	13.97	13.83	13.35
% VFA	75	74.8	75.2	75.8

Table 8 Characteristics of O.OPC.C mix

Characteristics	Results	Specification limits
Stability (kg)	1545	> 900 kg
Flow (mm)	3.1	2-4 mm
Stiffness (kg/mm)	498	300-500 kg/mm
Specific gravity (g/cm^3)	2.395	--
% V_a	3.28	3-5 %
% VMA	13.35	--
% VFA	75.8	--

5.2. Optimum hydrated lime content (O.HL.C)

Four HMA mixtures with the chosen materials, the OAC (5.2%), and percentages of HL (25, 50, 75, 100%) were prepared. The method of Marshall mix design was performed to calculate the optimum hydrated lime content (O.HL.C), resulting in a value of 25%. Table 9 displays the results of Marshall test for the percentages of HL, whereas table 10 displays O.HL.C mix characteristics.

Table 9 Characteristics of hydrated lime mixes

Characteristics \ Mix. No.	M5	M6	M7	M8
Stability (kg)	1396	1294	1173	1043
Flow (mm)	3.4	3.7	3.9	4.2
Stiffness (kg/mm)	411	350	301	248
Specific gravity (g/cm^3)	2.368	2.348	2.329	2.316
% V_a	3.54	3.71	3.92	4.23
% VMA	14.25	14.97	15.66	16.1
% VFA	75.16	75.22	74.96	73.73

Table 10 Characteristics of O.HL.C mix

Characteristics	Results	Specification limits
Stability (kg)	1396	> 900 kg
Flow (mm)	3.4	2-4 mm
Stiffness (kg/mm)	411	300-500 kg/mm
Specific gravity (g/cm^3)	2.368	--
% V_a	3.54	3-5 %
% VMA	14.25	--
% VFA	75.16	--

6. Influence of ordinary Portland cement percentage on Marshall characteristics

6.1. Influence of ordinary Portland cement percentage on stability

Table 7 presents that the stability of the OPC mixtures increased as the OPC percentage was increased. The stability increased to 1368 kg at 25% OPC (M1), achieving a 5% increase in comparison with M0. For the two following mixtures (M2 and M3), as the OPC percentage was increased, the stability increased to 1476 kg at 75% OPC, achieving a 12% increase in comparison with M0. For the following mix (M4), also as the OPC percentage was increased, the stability increased to its highest value of 1545 kg at 100% OPC, achieving a 16% increase in comparison with M0. Therefore, it can be noted that the substitution of LD by OPC had an obvious influence on the stability at the substitution percentage of 100%.

6.2. Influence of ordinary Portland cement content on flow

The values of flow for the examined mixes are displayed in table 7. The desired value of flow was 3.1 mm, corresponding to the highest stability value at 100% OPC (M4). This value decreased the flow by 14% in comparison with M0. The highest value of flow was 3.5 mm at 25% OPC percentage (M1).

7. Influence of hydrated lime percentage on Marshall characteristics

7.1. Influence of hydrated lime percentage on stability

Table 9 presents that the stability of the HL mixes decreased as the HL percentage was decreased. The stability attained its highest value of 1396 kg at 25% HL (M5), achieving a 7% increase in comparison with M0. For the two following mixes (M6 and M7), as the HL percentage was increased, the stability reduced to 1173 kg at 75% HL, achieving a 10% reduction in comparison with M0. For the following mix (M8), also as the HL percentage was increased, the stability of mix reduced to its lowest value of 1043 kg at 100% HL, achieving a 20% reduction in comparison to M0. Therefore, it can be noted that the substitution of LD by HL has an obvious influence on the stability at the substitution percentage of 25%.

7.2. Influence of hydrated lime percentage on flow

The values of flow for the examined mixes are displayed in table 9. The desired flow value was 3.4 mm, corresponding to the highest stability value at 25% HL (M5). This value reduced the flow by 6% in comparison with M0. The highest value of flow was 3.9 mm at 75% HL percentage (M3). Mix M8 lay out of the specification for flow value (> 4 mm) in accordance with the Egyptian code [4].

8. Stability loss test

The stability loss percent was taken as an index for the durability of the mix under various conditions. Marshall samples are kept in a water bath and tested at different times (0, 1, 2, 3 days) to calculate the stability loss for mixes as shown in Figs. 2 and 3. Figure 4 displays the stability loss percent versus immersion time for the selected mixes: Reference Mix, Comp. Mix. 1, and Comp. Mix. 2. The three main mixes exhibited values of stability loss within an desired range (< 25%) [6].

The reference mix presented the lowest loss percent. The stability loss increased to 21% for Comp. Mix. 1, achieving a 9.5% increase in comparison with the reference mix. The stability loss increased to a highest ratio of 23% for Comp. Mix. 2, achieving a 8.6% and 17% increase in comparison with the Comp. Mix. 1 and reference mix respectively. Therefore, it can be noted that substitution of LD by OPC had an obvious influence on the stability at its optimum percent of 100%, in comparison with HL at its optimum percentage of 25%.

Fig. 3 Marshall samples in water

Fig. 2 Bath of water

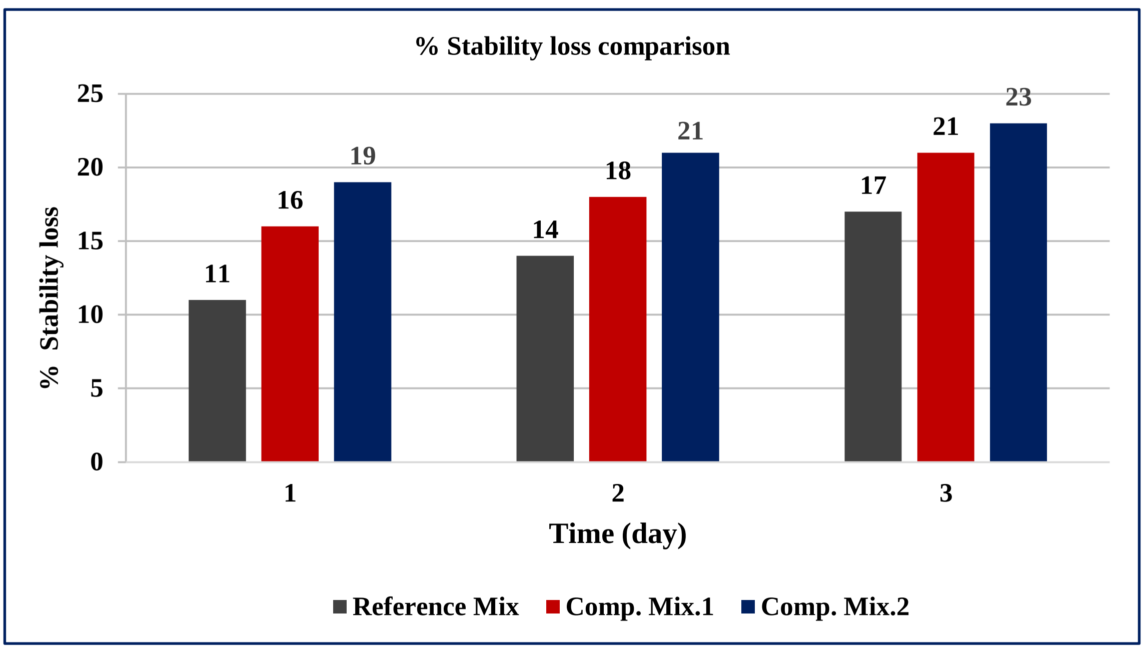

Fig. 4 Stability loss percent with time

9. Wheel tracking test

The wheel tracking test was performed on three samples in accordance with the Egyptian code [4]. This test was conducted on three mixes: Reference Mix, Comp. Mix. 1, and Comp. Mix. 2 to investigate the influence of OPC and HL on the ability of pavement to resist rutting. Figure

5 displays the machine of wheel tracking test. A slab of dimensions 44 cm × 33 cm × 5 cm according to LTG2015 [6, 7] was prepared for each mix and applied to the test at 60 ºC under wheel load as shown in Fig. 6. The track depth was reported at constant periods by using dial gauge up to 45 min. Figure 7 displays compacted slab after testing. Fig. 8 displays the rutting test results for the three main mixes.

Based on these results, the reference mix presented the highest rutting depth value (4.5 mm). The depth of rutting reduced, attaining the lowest value of 3.2 mm for Comp. Mix. 1, achieving a reduction of 30% in comparison with the reference mix. The depth of rutting was higher than that of Comp. Mix. 1 by 22% for Comp. Mix. 2, achieving a reduction of 9% in comparison with the reference mix. Based on these results, it can be noted that substitution of LD by OPC had an obvious influence on the stability at its optimum percentage of 100%, in comparison with HL at its optimum percentage of 25%.

Fig. 6 Slab under wheel load

Fig. 7 Compacted slab after testing

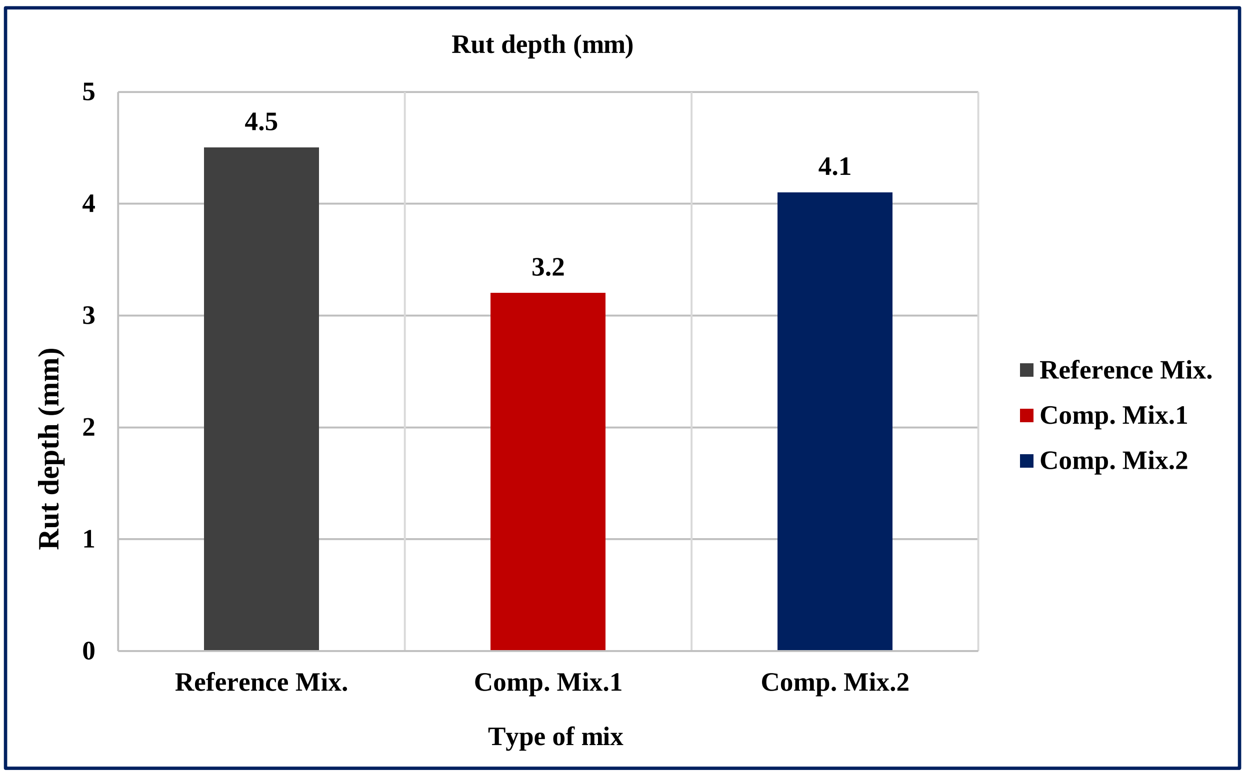

Fig. 8 Rut depth of each mix

Fig. 9 Indirect tensile strength test

10.Indirect tensile strength test

Tensile properties of asphalt mixes are evaluated in accordance with (AASHTO T 283) [8]. Marshall sample was loaded at a constant rate along its diametric plan. To investigate the pavement performance, the indirect tensile mode can be used to establish the tensile characteristics of asphalt mixes. Figure 9 displays the indirect tensile strength test. Two sets of the three main mixes were prepared. One set is conditioned by immersing it in a bath filled with water at 60 ºC for 24 h. The other set is used as unconditioned mixes. The percent of the indirect tensile strength of the conditioned specimens over the average indirect tensile strength of the unconditioned specimens is reported as the tensile strength ratio (TSR) which identified at least 80% [9]. Figure 10 displays the comparison of mixes results.

Based on these results, the reference mix had the lowest value of TSR (84.2%). The TSR increased and attained the highest value (89.6%) for comp. mix.1. Therefore, the TSR increased by about 6% in comparison with the reference mix. For comp. mix.2, the TSR was lower than that one of comp. mix.1 by 2% but this value was higher than that one of reference mix by 4%. Therefore, it can be noted that substitution of LD by OPC had an obvious influence on the resistance of moisture damage phenomena at its optimum percentage of 100%, in comparison with HL at its optimum percentage of 25%. According to this discussion, it could be noted that the performance of OPC additives in HMA mixes displayed a desirable performance in comparison with HL additives.

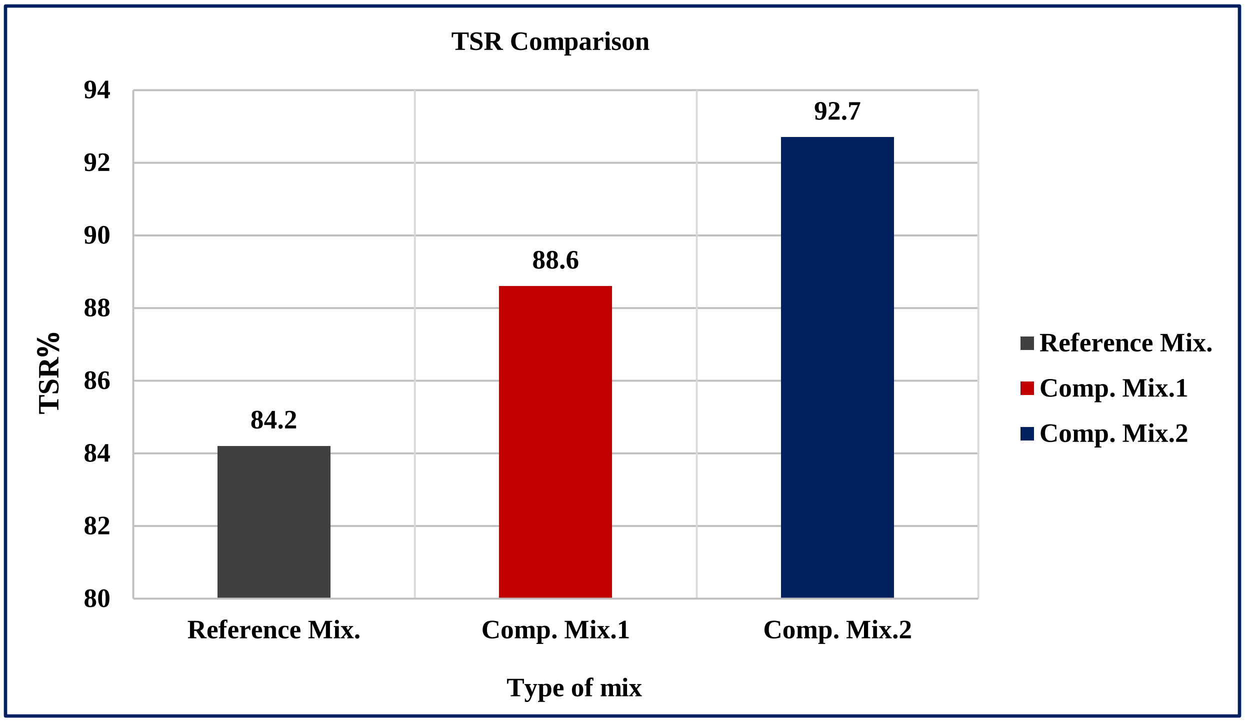

Fig. 10 Tensile Strength Ratio (TSR) for the three main mixes

11.Conclusions

Based on the results of this study, the following conclusions can be drawn:

1. The optimum percentage of OPC was 100% by filler weight instead of LD in the enhanced asphalt mixture.
2. The best percentage of HL was 25% by filler weight instead of LD in the enhanced asphalt mixture.
3. The asphalt mixture with OPC percentage of 100% attained a value of stability about 16% higher than that of the reference mix. In addition, this percentage attained a flow value about 14% lower than that of the reference mix.
4. The asphalt mixture containing HL at percentage of 25% attained a value of stability 7% higher than that of the reference mix. In addition, this percentage attained a value of flow about 6% lower than that of the reference mix.
5. The value of stability loss increased when using OPC and HL, in comparison with the reference mix. However, it existed in the desirable range (<25%) at the percentage values of 100% for OPC or 25% for HL.
6. Utilization of OPC and HL at their optimum percentages of 100 and 25%, respectively, had a significant influence on the rutting resistance.

7. Utilization of OPC at its optimum percentage (100%) instead of LD was better in comparison with use of HL at its optimum percentage of 25%, increasing the value of stability by about 10% and reducing the value of flow by about 9%.
8. Generally, a mixture was desired and prepared with 100% OPC by filler weight. This mix provided desirable values for almost all mix characteristics and therefore is recommended.

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