Investigative tests on the performance of asphaltic mixtures modified by additive combinations (hydrated lime and polypropylene)

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Abstract. Scientists and engineers are constantly trying to improve the performance of asphalt mixtures, and a wide range of modifiers are utilised to enhance HMA characteristics against damage such as rutting, aggregate stripping, and cracking.

The major objective of this research is to evaluate the performance of flexible pavement using asphalt from the Al- Daurah refinery with two locally additive, hydrated lime and polypropylene. Hot mix asphalt specimens were prepared with aggregate, of nominal maximum size 25 mm (base course) and 19 mm (binder course).

Cement is usually utilised as an HMA filler, and a percentage of Portland cement was used in this work, at 5% for the base course and 6% for the binder course. Polypropylene was used as additive with percentages of 1, 2, and 3% by weight of asphalt, and hydrated lime was used in a dry state at a percentage of 1% by weight of aggregate as a part replacer of filler.

The main mechanical characteristics of asphalt mixtures were evaluated using the Marshall index of retained strength and indirect tensile strength tests. Using hydrated lime and polypropylene caused the results of Marshall tests and indirect tensile tests to increase by 1.3 and 1.5 times, respectively, compared with the control mixture, while the index of retained strength test increased by 1.3 times compared with the control mixture. In particular, the addition of a combination of 1% hydrated lime by weight of aggregate and 2% polypropylene by weight of asphalt-to-asphalt mixtures satisfied the requirements for stability, moisture sensitivity, and indirect tensile strength.

Keywords: Hot Mix Asphalt, Additive Combination, Filler Addition, Marshall Test, Index of Retained Strength Test, Indirect Tensile Strength Test.

1. Introduction

Asphalt pavement, when designed and constructed properly, will provide years of service. Pavements do, however, continually undergo various types of stresses which cause small or large amounts of damage to the HMA layer. Traffic loading, structural issues, sub grade movement, weathering, moisture, and aging can all induce stresses that may lead to the layer's failure. The major disadvantages of asphaltic concrete pavements are thus that they are greatly influenced by environmental changes. High ambient temperatures soften asphalt binders and reduce HMA stiffness, leading to rutting, while low ambient temperatures stiffens the binder and reduce HMA flexibility, leading to cracking. Thus, high temperature stiffness and low temperature flexibility are important characteristics that increase the lifetime of HMA layers [1].

Asphalt binders must therefore have high softening temperatures to reduce the chance of permanent deformation and must have proper penetration values to reduce sensitivity to cracking. The addition of polymers as asphalt modifiers can thus enhance HMA lifetime and reduce the need for maintenance. The addition of polymer polypropylene combined with minor amounts of hydrated lime to base asphalt produces modified asphalt mixtures with higher Marshall stability and flow values, and better indirect tensile strength and fatigue life values [2, 3].

Many admixtures can be used in asphaltic materials, both directly and indirectly. Hydrated lime, one of the most important additives, has a positively effect in reducing the rutting of asphaltic mixtures by improving the bonds between asphaltic materials and aggregates. However, other researchers have
also noted the development of resistance against asphalt cracking such that the crack and rut resistant properties of mixtures are enhanced by a certain amount, when adding HL [4]. Polymers are the most common asphalt modifier, and these improve the mechanical properties of the mixture, reducing rutting, cracking, and moisture damage [5]. This paper focuses on addressing the main common problems of HMA layers in many regions of this country, which include rutting, fatigue cracking, and moisture damage.

2. Experimental work

2.1 Material used

Material utilised in this paper were all locally available and included coarse and fine aggregates, filler, asphalt cement, and additive.

2.1.1 Asphalt Cement

Daurah asphalt binder (40-50) with the following characteristics was utilised, as shown in Table 1.

| Test | Units | Penetration grade 40-50 | S.C.R.B Specification (2009) |
|------|-------|------------------------|-----------------------------|
| Penetration (25 °C), 100 gm, 5 sec | 1/10 mm | 44 | (40-50) |
| Kinematic Viscosity at 135 °C | cst | 380 | ----- |
| Ductility (25 °C, 5 cm/min) | cm | 104 | >100 |
| Flash Point ASTM D-92 (Cleveland open cup) | °C | 335 | min. 232 |
| Specific Gravity at 25 °C | …… | 1.03 | (1.01-1.05) |

(* ) These tests were carried out in the highway materials laboratory of the Civil Engineering Dept., Babylon University and Daurah Refinery.

2.1.2 Aggregates

Al-Najaf crushed gravel was used in the mixtures. This is commonly used in the middle and south of Iraq for pavement layers. The particles are off white in colour, with pronounced angularity. The fine and coarse aggregates were sieved and recombined in the proper proportions to meet the gradations required by SCRB specifications. Tests were carried out on the aggregates to evaluate their physical characteristics. The results and the specification limits as set by the SCRB are summarised in Table 2.
The gradations of aggregate were a nominal maximum size of 25 mm and 19 mm as presented in Table 3. The test results showed that the chosen aggregates met the SCRB specifications.

Table 2. Physical Characteristics of Aggregate

| Property                     | ASTM Designation | Coarse aggregate | Fine aggregate |
|------------------------------|------------------|------------------|----------------|
| Bulk specific gravity        | C-127 C-128      | 2.55             | 2.64           |
| Apparent specific gravity    | C-127 C-128      | 2.65             | 2.67           |
| % water absorption           | C-127 C-128      | 0.83             | 0.65           |
| Abrasion (Los Angeles)       | C-131            | 26 % Max 30 %    | 0.076          |
| Angularity                   | D-5821           | 95 %             | 0.076          |

(*) These tests were carried out in the highway materials laboratory of Civil Engineering Dept., Babylon University

Table 3. Asphalt mixture grading for base and binder courses

| No. | Sieve size (mm) | Specification limits for base course (SCRB-2009) | Specification limits for binder course (SCRB - 2009) |
|-----|-----------------|--------------------------------------------------|---------------------------------------------------|
|     | Standard sieves | English sieves (in)                              |                                                   |
| 1   | 37.5            | 1/2 1                                           | 100                                               |
| 2   | 25.0            | 1                                               | 90-100                                           |
| 3   | 19.0            | 3/4                                             | 76-90                                            |
| 4   | 12.5            | 1/2                                             | 56-80                                            |
| 5   | 9.5             | 3/8                                             | 48-74                                            |
| 6   | 4.75            | No. 4                                           | 29-59                                            |
| 7   | 2.36            | No. 8                                           | 19-45                                            |
| 8   | 300 µm          | No. 50                                          | 5-17                                             |
| 9   | 75 µm           | No. 200                                         | 2-8                                              |

2.1.3. Mineral filler

In this research, Portland cement was used as a filler at percentages of 5% for base course and 6% for binder course. The physical characteristics of the filler are shown Table 4.

Table 4. Physical characteristics of the used filler

| Property         | Cement |
|------------------|--------|
| Specific gravity | 3.10   |
| Fineness (cm²/gm)| 3080   |
| % passing sieve No. 200 | 96    |
(*) These tests were carried out in the highway materials laboratory of Civil Engineering Dept., Babylon University.

2.1.4 Additives

2.1.4.1 Hydrated lime

Hydrated lime was used in a dry state at a percentage of 1% by aggregate weight. This HL content was chosen for workability. The physical characteristics of hydrated lime are presented in Table 5.

| Property            | H. lime |
|---------------------|---------|
| Specific gravity    | 2.45    |
| Fineness (cm²/gm)   | 3870    |
| % passing sieve No. 200 | 100    |

(*') These tests were carried out in the highway materials laboratory of Civil Engineering Dept., Babylon University.

2.1.4.2 Polypropylene Fibre (PP)

Polypropylene was used in a wet state at percentages of 1, 2, and 3% by weight of asphalt, with a blending speed of 2,620 rpm, temperature of 150 °C, and time of 60 minutes [6]. The characteristics of polypropylene are presented in Table 6.

| Form                        | Virgin Polypropylene Fibre |
|-----------------------------|----------------------------|
| Specific gravity            | 0.91                       |
| Alkali content              | Nil                        |
| Sulphate content            | Nil                        |
| Chloride content            | Nil                        |
| Fibre thickness             | (18 – 30) microns          |
| Young modulus               | (5500 – 7000) MPa          |
| Tensile strength            | 350 MPa                    |
| Melting point               | (150 – 160) °C             |
| Fibre length                | (6 – 12) mm                |

* These results were obtained in the SPSI laboratory.

2.2 Test Methods

The test methods used in this research aimed to evaluate the behaviour of different HMAAs and thus included Marshall, indirect tensile, and index of retained strength tests.

2.2.1 Marshall Test

The standard method of Marshall testing, as used in [7] was used for the compacted asphalt concrete specimens. Test specimens were fabricated with a range of asphalt contents of 3 to 5.5% for the base course and 4 to 6% for binder course. The optimum asphalt content selected for the design was essentially a compromise value that met the specified requirements for stability, flow, and voids in the total mix (VTM) [8].

It was found that the optimum asphalt content required was 4.5% for the base course and 4.8% for the binder course. The Marshall apparatus and compaction apparatus are shown in Figure 1. Iraqi specifications [9] require specific values for base and binder layers, as presented in Table 7.
Table 7. SCRB Specification of HMA mixes

| Properties                        | S.C.R.B (2009) Specification Limits for base course | S.C.R.B (2009) Specification Limits for binder course |
|-----------------------------------|-----------------------------------------------------|------------------------------------------------------|
| Marshall stability, kN            | 5 (minimum)                                         | 7 (minimum)                                          |
| Marshall flow, mm                 | 2 – 4                                               | 2 – 4                                                |
| Air voids, %                      | 3 – 6                                               | 3 – 5                                                |
| Void in mineral aggregate, %      | 12 (minimum)                                        | 13 (minimum)                                         |

Figure 1. Marshall Apparatus and Compaction Apparatus, Highway Materials Laboratory, Civil Engineering Dept., Babylon University

2.2.2 Indirect Tensile Test (IDT)
Tests of indirect tension were made as in [10] to measure the creep and strength property of the asphaltic mixes. Specimens were placed in a water bath at 20 °C for 30 minutes before loads were applied at a constant rate of 2.5 inch/min to test compressive strength across the diagonal axis of samples until failure. Observing the failure type, helped with recognising the crack mechanism of various tested mixes, whether along the loading axis or at the transverse axis. The dimensions of the samples were 4 inches (101.6 mm) diameter and 2.5 inches (63.5 mm) height. In the road laboratory of the civil engineering, department of the University of Babylon, a Marshall apparatus was used to conduct the test by replacing the device head with two metal brackets of 0.5 inch (12.5 mm) width, as shown in Figure 2.
Figure 2. Converting Marshall Test to Measure Indirect Tensile Strength, Highway Materials Laboratory, Civil Engineering Dept., Babylon University

The results of indirect tensile methods were obtained using the equation below [11, 12]:

$$\sigma = \frac{2P}{\pi t D}$$  \hspace{1cm} (1)

where
\(\sigma\) = Tensile strength (MPa);
\(P\) = Peak load (N);
\(t\) = Thickness of specimen (mm); and
\(d\) = Diameter of specimen (mm).

2.2.3 Immersion Compression Test (index of retained strength)
This test was done for HMA specimens with all adopted variables. Two types of samples were prepared: the first were submerged in water for conditioning and second in a dry state. This allowed measurement of the moisture susceptibility of the mixtures [13]. The compression apparatus is shown in Figure 3.

Figure 3. Compression apparatus, Highway Materials Laboratory, Civil Engineering Dept., Babylon University.

3. Results and discussions
3.1 Marshall Test
Stability is a significant parameter for any asphalt mixture used in base and binder course design, as it represents the ability to resist rutting under traffic. Almost all of the stability results of treated asphalt concrete mixtures, regardless of additive type and percentage of filler combination were higher than those seen in control HMA.
Air void content is a significant parameter because it permits the characteristics and behaviours of the mixture to be predicted in terms of the service life of the pavement [14].

- The results of the control mixtures meet Iraqi specifications [15] with stability minimum of kN to 7 kN, flow range of 2 to 4 mm and air voids range of 3 to 6 and 3 to 5 for base and binder courses, respectively.
- The best combination in terms of stability indicators was 1% hydrated lime, 2% polypropylene, while other combinations (1% hydrated lime, 1% polypropylene and 1% hydrated lime, 3% polypropylene) still met Iraqi specifications, but with lower values.
- The best combination for the content of air void value was 1% hydrated lime, 2% polypropylene. The air voids value of the NMAS was about 25 mm in a mixture which contained a combination of 1% hydrated lime, 3% polypropylene; however, this exceeded the limitation of 3 to 6% due to the higher concentration of plastomer (polypropylene) while the combination of 1% hydrated lime, 1% polypropylene met Iraqi specifications but with higher values. The results of the Marshall test are shown in Table 8.

**Table 8. Marshall tests results**

| Type of Mix | N.M.A.S (mm) | Mix Symbol | Stability (kN) | Flow (mm) | Stiffness (kN/mm) | Air Void % |
|-------------|--------------|------------|----------------|-----------|------------------|------------|
| (Control)   | 25           | A1         | 7.2            | 2.8       | 2.571            | 5.3        |
|             | 19           | A2         | 8.9            | 3.4       | 2.618            | 4.3        |
| 1% HL & 1% pp | 25        | A3         | 8.1            | 3.1       | 2.613            | 5.0        |
|             | 19           | A4         | 10.2           | 3.6       | 2.833            | 4.4        |
| 1% HL & 2% pp | 25        | A5         | 9.9            | 3.3       | 3.300            | 4.7        |
|             | 19           | A6         | 11.6           | 3.5       | 3.314            | 4.2        |
| 1% HL & 3% pp | 25        | A7         | 7.9            | 3.6       | 2.194            | 6.1        |
|             | 19           | A8         | 9.1            | 3.9       | 2.333            | 4.9        |

3.2 Indirect Tensile Strength

Various traffic and climate conditions affect asphaltic pavement. Fatigue cracking due to traffic and shrinkage cracking due to climate are among the most common. As mentioned previously, one testing temperature was set to evaluate the resistance of mixtures at 20 °C. In the tensile stress state, the mixture strength depends on the cohesion element (asphalt) resisting stresses [16, 17].

The best combination was found to be 1% hydrated lime, 2% polypropylene for indirect tensile strength while other combinations (1% hydrated lime, 1% polypropylene and 1% hydrated lime, 3% polypropylene) had lower values. The addition of plastomers such as polypropylene modifies asphalt by forming a tough and rigid network within the binder that resists deformation in agreement with [17]. Even the addition of only 1% HL helps to stiffen the mixture and increases the resistance to rutting and fatigue cracking, in agreement with [18]. The results of the indirect tensile strength test are shown in Table 9.

**Table 9. Indirect tensile strength test results**

| Type of Mixture | N.M.A.S (mm) | Mix Symbol | Indirect Tensile Strength (MPa) |
|-----------------|--------------|------------|--------------------------------|
| (Control)       | 25           | A1         | 1.436                          |
|                 | 19           | A2         | 1.329                          |
| 1% HL & 1% pp   | 25           | A3         | 1.611                          |
|                 | 19           | A4         | 1.796                          |
| 1% HL           | 25           | A5         | 1.772                          |
3.3 Index of Retained Strength Test

Moisture-related problems are due to, or accelerated by, moisture accumulation on pavements. Polymers related to the moisture susceptibility of mixtures can be used as modifiers against adhesion failure or cohesion failure. While adhesion failure occurs due to the stripping of asphalt from gravel and sand surface, this reflects a loss of strength of the asphaltic mixture [11, 12].

Iraqi specification (General Specification for Roads and Bridges Section R9) R9/5 specifies that the IRS must be 70% minimum for mixtures with all NMAS (whether base or binder). This test is considered to be an indication of moisture damage sensitivity.

The results for all control mixtures did not meet Iraqi specification. The best combination was 1% hydrated lime, 2% polypropylene for the index of retained strength ratio, while other combinations (1% hydrated lime, 1% polypropylene and 1% hydrated lime, 3% polypropylene) did meet Iraqi specifications, but with lower values. Adding PP increases the adhesion between aggregate and asphalt, which leads to a decrease in the stripping of HMA and in the horizontal deformation, as well as to an increase in the tensile stiffness modulus values that agrees with [19].

The use of HL as an additive helps in several mechanical and chemical ways in terms of reducing moisture damage and improving stiffness. This can be achieved by using only 1% of HL, which reacts chemically with asphaltic material and changes the medium from acidic to basic, creating stronger bonds between asphaltic mixture contents [20, 21].

The results of the index of retained strength ratio test are shown in Table 10.

| Type of Mixture | N.M.A.S (mm) | Mix Symbol | Index of retained strength % |
|----------------|-------------|------------|-----------------------------|
| (Control)      | 25          | A1/2       | 59.5/62.4                   |
| 1% HL          | 25          | A3/4       | 77.6/93.8                   |
| & 1% pp        | 19          | A3/4       | 77.6/93.8                   |
| 1% HL          | 25          | A5/6       | 78.5/97.0                   |
| & 2% pp        | 19          | A7/8       | 67.7/72.3                   |
| 1% HL          | 25          | A7/8       | 67.7/72.3                   |
| & 3% pp        | 19          | A8         | 72.3                        |

4. Conclusions

From the results of the experimental work the following conclusions can be drawn:
- Using hydrated lime together with polypropylene as modifiers for HMA allows significant enhancement of characteristics for mixes of 25 mm maximum size and 19 mm maximum size.
- Using the stability test as an indication of rutting issues, the best combination was 1% hydrated lime, 2% polypropylene, which increased the stability value by 1.3 times.
- The use of a combination of additives (1% hydrated lime, 2% polypropylene) achieved satisfactory values of Marshall stiffness with an increment of 1.25 times that of modified HMA.
- The addition of hydrated lime in the HMA mixture with any polymer combination decreased the % air voids by 1.2 times.
- Using the index of retained strength test as an indication of moisture damage issues, the use of hydrated lime as an additive to HMA in a polymer combination significantly increased the index of retained strength by 1.3 times.
Using the indirect tensile strength test as an indication of possible fatigue cracks, the best combination (1% hydrated lime, 2% polypropylene) increased the indirect tensile strength value by 1.5 times.

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