Improving Mechanical Properties of Hot Mix Asphalt Using Fibres and Polymers in Developing Countries

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Abstract. The enhancement of mechanical properties and long term performance of hot mix asphalt (HMA) should be considered as a goal in order to achieve a transport infrastructure really sustainable. However, this issue becomes a difficult task, if conventional HMA are used. In fact, performance of conventional HMA, usually presents poor long term performance and functional distresses related to high and low temperatures, which in turn implies higher maintenance costs and superior carbon footprints. To overcome this weaken, bitumen industry has been developing new polymer modifiers, additives to improve HMA behaviour. One of the techniques most used in developed countries to enhance HMA behaviour is the use of modified bitumen. Modifying the bitumen, and then producing modified HMA requires specific equipment and facilities that may be time-consuming, expensive and hard to manage. For instance, to warranty a successful modifying process, storage and handling of the modified bitumen are issues very complex to handle. On the other hand, producing a polymer modified HMA by adding polymers and additives directly during the bitumen/aggregate mixing process may offer very interesting advantages since the economical, production and sustainability standpoint. This paper aimed to determine the feasibility of the incorporation of fibres and plastomeric polymers into different types of HMA by means of the “dry process” (to add polymers during the mixing of aggregate and bitumen in the HMA plant) to produce polymer modified mixes. Thus, laboratory tests including Marshall Stability, Indirect Tensile Stiffness Modulus, repeated load test and Indirect Tensile Strength test were performed to assess the effect of the inclusion of fibres and plastomeric polymers on mechanical and volumetric properties of selected mixes. Results showed that the modification of bituminous mixtures following the “dry process” could be used to improve the performance and long term properties of HMA.

1. Introduction

In recent years, the advance of technology in the field of asphalt paving materials has mainly focused on developing solutions to pavement distress such as permanent deformation, moisture damage, and fatigue or low-temperature cracks, in order to extend the pavement durability. As a solution, pavement technologists have developed asphalt mix additives for mitigating those distress in hot mix asphalt (HMA). In general, there are different additives available, which can be introduced directly to the bitumen, i.e., wet process, as a binder modifier, or blended directly with the aggregates, i.e., dry process [1-3]. Among the main additives, fibres, hydrated lime, Portland cement, and polymers are the most common additives used for improving moisture susceptibility, rutting resistance, stability, and other mechanical properties of HMA. Within polymers, elastomer polymers are mostly used for enhancing...
the resilient behavior, i.e., the ability of mixtures to recover deformation that they experience when subjected to loading and unloading cycles. Moreover, plastomeri c polymers are used for stiffening and improving the performance grade of HMA at high temperatures [4].

Despite the benefits of HMA modification, those practices are not usually adopted by pavement constructors in developing countries such as Colombia, especially when using the dry-process. Based on the above mentioned facts, the present research aims to determine the feasibility of incorporating a compound of fibre and plastomeric polymers in HMA. This study presents an experimental performance evaluation of three types of unmodified mixes prepared using local aggregates with different physical and mineralogical properties and three modified mixes. In the first place, the Marshall Mix design was conducted for each one of the 3 modified mixes in order to determine the optimum binder content (OBD). Then, mixes without additive were prepared and Marshall Stability, Indirect Tensile Stiffness Modulus, Repeated load test and Indirect Tensile Strength test were performed to analyse the effect of the additive on the mechanical performance of the mixes.

2. Materials and experimental program

Three different mixes, characterized by different grain size distribution and different aggregates were considered in this investigation. Unmodified mixes were compared to additive modified ones in terms of Indirect Tensile Strength, Stiffness Modulus and Repeated Load test, to analyse how additive addition influences material performance. In the present section, material characterization, specimen preparation process and testing procedures are presented.

2.1. Bitumen

The bitumen used in this study was a 60/70 dmm penetration grade bitumen supplied by a Colombian refinery. Conventional laboratory tests including softening point, penetration and rotational viscosity were performed on the neat bitumen in order to assess their physical properties, as reported in Table 1. Figure 1 shows the viscosity curve of bitumen.

| Table 1. Physical properties of the bitumen |
| Softening Point (ºC) | Penetration (dmm) | Penetration Index | Rotational Viscosity @ 135 ºC (Pa*s) | Rotational Viscosity @ 160 ºC (Pa*s) |
|----------------------|-------------------|------------------|-----------------------------------|-----------------------------------|
| Base binder          | 48.7              | 54.9             | -1.3                              | 0.349                             | 0.118                             |

![Figure 1. Viscosity curve of asphalt binder used](image-url)
2.2. Additive
The additive used is a compound of different stabilizing microfibres and plastomeric polymers. According to the manufacturer’s instructions, the additive was added to hot aggregates with a dosage of 0.5% by weight of dry aggregates before adding the bitumen. Figure 2 displays the physical appearance of the additive.

![Figure 2](image1.png)

**Figure 2.** Physical appearance of the additive. a) Normal appearance b) Microscopic appearance at 25X

2.3. Aggregates
In order to study the behaviour of the additive in HMA, three types of mixtures were carried out with different types of aggregates from different sources. Mix A was designed mainly with river aggregates, Mix B with aggregates from hard rock quarries and Mix C with river aggregates. To verify that aggregates satisfy the minimum requirements prescribed by INVIA S regulation [5], laboratory tests including: granulometry (INV E 123), shape index (INV E 230), sand equivalent (INV E 133), and resistance to degradation (INV E 238) were performed on the aggregates. Figure 3 shows the gradation curve of each mix.

![Figure 3](image2.png)

**Figure 3.** Gradation curve of the mixes studied
2.4. Asphalt mix preparation
The asphalt mix design was based on the Marshall method, which is the official method required by the Colombia’s National Highway Institute (INVIAS) [5] and adopting a heavy traffic category (NT3). According to basic requirements of INVIAS for heavy traffic, the mixtures must have a minimum stability of 9.0 kN, flow between 2.0 and 3.5 mm, minimum voids in the mineral aggregate (VMA) of 14%, voids in the total mix between 4.0 and 6.0%, and voids filled with asphalt between 65 and 75%.

2.5. Marshall mix design. The Marshall Mix design method was used on modified mixes, in order to determine the optimum bitumen content. Before the mixing process, the aggregates were oven heated at 100 ºC in order to ensure no water content. The aggregates were oven heated until they reached the mixing temperature (175 ºC). After that, the polymeric compound was poured in the mixer and mixed with aggregate. This temperature was selected according to the additive manufacturer’s recommendations. Then, when aggregate and additives reached the equviscosity mixing temperature, bitumen was poured into the mixer, until a uniform distribution of the bitumen was observed. Finally, specimens with dimensions of approximately 4.0-inch diameter and 2.5 inch height were compacted using a Marshall hammer at 75 blows per side and at (150ºC). Mechanical and volumetric properties of all specimens were obtained after a curing period of 24 h.

Four percentage of bitumen were tested for each mixture (A, B and C). After the optimum bitumen content was determined, mixes without additive were prepared, in order to assess the influence of the additive in the volumetric and mechanical properties. However, the compaction temperature remained the same for both types of mixes. The optimum binder content, mechanical and volumetric properties of each unmodified mix are reported in table 2. According to these results, the designed mixes meet the most of the requirements specified by INVIAS.

Table 2. Mechanical and volumetric properties of unmodified mixes

| Mix | Optimum binder content (%) | Stability (kN) | Flow (mm) | Voids in the total mix (%) | Voids in the mineral aggregate (%) | Voids filled with asphalt (%) | Gmb |
|-----|---------------------------|----------------|-----------|--------------------------|----------------------------------|-------------------------------|-----|
| A   | 5.10                      | 18.16          | 6.04      | 3.68                     | 15.53                            | 76.30                         | 2.393|
| B   | 5.00                      | 19.15          | 5.66      | 6.27                     | 17.54                            | 64.29                         | 2.320|
| C   | 5.00                      | 23.39          | 6.05      | 4.80                     | 16.80                            | 71.50                         | 2.333|

2.6. Laboratory tests

2.6.1. Marshall Stability. This test was performed in order to evaluate the effect of the fibres on Marshall flow and Stability, as main criteria for the mechanical evaluation of the mixtures adopted by INVIAS. The test was performed at a strain rate of 50 mm/min and at a temperature of 60 ºC, according to INVE – 748 standards. In addition to that, the ratio of stability to flow, stated as the Marshall quotient (MQ), was determined as an indicator of the stiffness of the mix. Hence, high Marshall quotient values indicate a high stiffness mix with higher ability to spread the applied burden. It is well recognized that the Marshall quotient is a measure of the materials resistance to shear stresses and permanent deformation [6].

2.6.2. Indirect Stiffness Modulus. The Indirect Tensile Stiffness Modulus (ITSM) test was performed in accordance with the method described in the European Standard EN 12697-26 (2004). This test has the capacity of measuring the viscoelastic response of a paving material. The specimens were placed in a controlled temperature chamber assuring that they reach a specified temperature (at least two hours before testing). The target diametric deformation of 5±2µm was imposed at each peak load for 100 mm nominal diameter specimens. The conditions of the test are reported as follows:
• Temperature: 20 and 40°C
• Load frequency: 2 and 8Hz

At least three specimens were tested for each level in ITSM mode.

2.6.3. Indirect Tensile Strength. The Indirect Tensile Strength (ITS) was performed according to the method described in the European Standard EN 12697 - 23 (2007). This test is used to determine the tensile properties of asphalt concrete which can be further related to the cracking properties of the asphalt pavement [7]. The test involves loading a cylindrical specimen with vertical diametric compressive loads at 50mm/min deformation rate. The indirect tensile strength of each specimen was determined using the following equation:

\[
\text{ITS} = \frac{2P}{\pi dt}
\]

Where, ITS = indirect tensile strength, \(P\) = peak load, \(d\) = diameter of the specimen, and \(t\) = thickness of the specimen.

The specimens evaluated under ITS were prepared using gyratory compaction method with a load of 600 kPa, 230 cycles and a rotation angle of 1.25º.

2.6.4. Repeated load test. The Repeated load test was performed in accordance with the method described in the European Standard EN-12697-25. This test is used to determine the permanent deformation of the asphalt mixtures, which is related to their rutting potential. The test was performed at 40 ºC with an axial stress of 500 kPa. A square pulse was applied with a 500-ms pulse width and 500-ms rest period for 3600 cycles. The strain was measured by using two linear variable displacement transducers (LDVTs). Prior to the test, a preload consisted of 600 s and axial stress of 10 kPa was applied according to the European Standard.

3. Results and discussions
In this section all the experimental results about stiffness modulus at different temperatures and frequencies, indirect tensile strength, permanent deformation resistance and Marshall Stability are described in details.

3.1. Indirect tensile stiffness modulus
The three control mixes, and the ones containing polymers are compared in terms of stiffness modulus at different temperatures. Results are reported in figure 4.

![Figure 4. ITSM results at 2Hz](image)
According to Figures 4 and 5, stiffness modulus is significantly affected by the incorporation of polymers. When comparing stiffness modulus of the mixes with and without additives, it can be observed that the additive tend to stiff the mix. This is probably due to polymer content [4]. Modified asphalt mixtures have a higher stiffness respect to the control mixtures; hence, the modification of mixtures with this additive may be considered as a viable alternative for areas where pavements are exposed to high temperatures.

![Figure 5. ITSM results at 8Hz](image)

### 3.2. Marshall Stability

The average Marshall Stability of the mixtures is presented in Figure 6. As shown, the additive increases the Marshall Stability of Mix A. Regard to Mix B, the additive slightly decreases the Marshall Stability of this mix. However, a significant reduction of Marshall Stability is observed in Mix C.

![Figure 6. Marshall Stability of unmodified and modified mixes](image)
This indicates that the effect of additive in Marshall Stability HMA depends on mix design characteristics (e.g. aggregate type and grading, and bitumen grade and amount). Then, it is believed that in some way, the additive modify of some intrinsic property of the mix that in conjunction with different aggregate source and grading, causes a different effect in Marshall Stability for each mix.

Figure 7 shows the Marshall Quotient of the mixtures. Additive addition tends to increase the MQ of mix type A and B. This result was expected because of polymer’s nature. As said before, high MQ values indicate a high stiffness mix, which is confirmed by the Indirect Tensile Stiffness Modulus test, and resistance to creep deformation. A different effect was registered for Mix C, where the additive seems to decrease the MQ value of the mix. However, this result is not evidenced when observing the stiffness modulus of Mix C. Indeed, a significant variation of stiffness modulus was not detected in Mix C after modification. This means that even though both MQ and ITSM are a measurement of stiffness, they are not correlated.

3.3. Indirect tensile strength

The average indirect tensile strength of the mixtures is given in Figure 8. According to the results, Mix A seems to be negatively affected by the incorporation of the additive. However, considering the values obtained from the Indirect Tensile Strength test in Mix B and Mix C, it seems that modified mixtures have higher resistance compared to control mixtures, especially for Mix B. Although the same binder was used for all three mixes, the mixes prescribed different properties (e.g. bitumen content, voids, VTM, etc.), which makes the influence of the additive different for each mixture. Based on the fact that fibres tend to increase the tensile strength of asphalt mixture, the results indicate that maybe additive proportion in Mix A was not accurate.

3.4. Repeated load test

According to the results from the Indirect Tensile Stiffness Modulus test, the mixes A and B clearly seemed to be affected by the addition of the additive, dissimilar to Mix C, where the effect of the additive is minimal. For that reason, the Repeated load test was only performed in Mix A and Mix B. The test was performed at a temperature of 40 °C as indicated in the British Standard.
Figure 8. Indirect tensile strength

Figure 9 presents the permanent deformations after submitting specimens to 3600 cycles at 500 kPa of axial stress. As shown in Figure 9, the modified mixtures exhibit a better performance of their axial deformation against a cyclic load. At the same load, the conventional mixtures have a permanent deformation of at least 1.5 times higher than a modified mixture; which indicates that a mixture modified with this type of additives will show a better performance in the case of rutting situations.

Figure 9. Repeated load test results

4. Conclusions

Laboratory test were performed on three different HMA with different sources of aggregates in order to determine the feasibility of incorporating an additive composed of fibers and polymers in HMA. The influence of the additive can be discussed as follows.

According to Indirect tensile stiffness modulus test results, the stiffness modulus of the modified mixtures is higher compared to the value of stiffness modulus of the control mixtures, it could result in a more resistant mixture with a lower layer thickness from the design and construction phase, and a better performance when the pavement is exposed to high temperatures. In addition, the modified mixtures also present a satisfactory behavior respect to permanent deformations when the cyclical loads are applied, it means that the use of this type of modification in the asphalt mixtures results in better performance off the pavement and it helps to reduce the possibility of rutting of the asphalt mixture. Beside this, it was found that the additive increase the tensile strength of the majority of the mixes.
However, a proper study should be conducted varying the dosification of the additive and the binder content in order to study the interaction between these parameters. Finally, the results obtained in this research indicate that the modification of asphalt mixtures using the dry process in Colombia could be used to improve the performance of the pavements throughout their service life, given the enhancement of the stiffness modulus, increase in bearing capacity and resistance to cracking by applied loads.

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