Ciencia e Ingeniería Neogranadina
2023
Vol. 33(2)
julio-diciembre de 2023 ▪ ISSN: 0124-8170 · ISSN-e: 1909-7735 ▪ pp. 119-130

Editorial Neogranadina

DOI: https://doi.org/10.18359/rcin.6970

Mechanical Assessment of a Warm Mix Asphalt (WMA) Using Additives Viscosity Modifiers

Carlos José Slebi Acevedo[a] ▪ Daniel Alberto Zuluaga Astudillo[b] ▪ Rafael Gutiérrez Melgarejo[c]

Abstract: Warm Mix Asphalt (WMA) technology has been a driving force in the asphalt industry, as it contributes to minimizing greenhouse gas emissions in the environment, aiding in the reduction of global warming and carbon footprint. In this research, the impact of two WMA additives on the characteristics of asphalt binder and asphalt mixture was experimentally assessed. Among the results, a notable impact of additives was observed on the viscosity property of the asphalt binder. Both additives reduce viscosity as the temperature in the mixture increased. Concerning asphalt mixtures, the addition of WMA additives tended to increase bulk density, voids filled with asphalt, Marshall stability, and reduce air voids content. The incorporation of these additives can lead to a reduction of 0.2 to 0.4% in the optimal bitumen content.

Keywords: additives, Sustainability, Viscosity, Warm Mix Asphalt WMA

Recibido: 06/10/2023 **Aceptado:** 27/11/2023 **Disponible en línea:** 27/12/2023

Cómo citar: C. J. Slebi Acevedo, D. A. Zuluaga Astudillo, y R. Gutiérrez Melgarejo, «Mechanical Assessment of a Warm Mix Asphalt (WMA) Using Additives Viscosity Modifiers», Cien.Ing. Neogranadina, vol. 33, n.º 2, pp. 119–130.December 2023.

* Investigation Article

a Ph. D. in Civil Engineering (emphasis on pavements), Master's in Civil Engineering (emphasis on geotechnics), Departament of Civil Engineering Geotechnical Studies Center Julio Garavito Colombian School of Engineering, Bogota, Colombia. Email: carlos.slebi@escuelaing.edu.co
ORCID: http://orcid.org/0000-0002-8544-0392

b Master's in Civil Engineering (Emphasis on Road Infrastructure), Master's in Civil Engineering (Emphasis on Geotechnics). School of Military Engineers, Bogota, Colombia. Email: daniel.zuluaga@esing.edu.co
ORCID: http://orcid.org/0000-0002-7823-9025

c Master's in Civil Engineering, Department of Civil and Environmental Engineering Florida International University, Miami, USA. Email: rguti120@fiu.edu ORCID: https://orcid.org/0009-0006-4997-5927

Evaluación mecánica de una mezcla asfáltica tibia (WMA) utilizando aditivos modificadores de viscosidad

Resumen: La tecnología de mezcla asfáltica tibia (WMA) ha sido un incentivo en la industria asfáltica ya que contribuye a minimizar las emisiones de gases de efecto invernadero al medio ambiente, ayudando a reducir el calentamiento global y la huella de carbono. En esta investigación se evaluó experimentalmente el impacto de dos aditivos WMA sobre las características del ligante asfáltico y la mezcla asfáltica. Entre los resultados, se destacó el impacto de los aditivos en la propiedad de viscosidad del ligante asfáltico. Ambos aditivos redujeron la viscosidad a medida que aumentaba la temperatura en la mezcla. Con respecto a las mezclas asfálticas, la adición de aditivos WMA tendió a aumentar la densidad aparente, los vacíos llenos de asfalto, la estabilidad Marshall y a reducir el contenido de vacíos de aire. La incorporación de estos aditivos puede reducir entre un 0.2 y un 0.4% el contenido óptimo de betún.

Palabras clave: aditivo; mezcla asfáltica tibia WMA; sostenibilidad; viscosidad

Introduction

Most roads worldwide have been constructed using hot mix asphalt (HMA). Due to its high manufacturing temperatures (between 140 and 190 °C. [1]), it generates large quantities of greenhouse gases (GHG) and increases the consumption of fossil fuels during the processes of manufacturing, transport, and laying [2]. In response to these envioromental impacts engineers and researchers have developed asphalt mixtures than can be produced and applied at reduced temperatures [3]. Warm Mix Asphalt (WMA) is described as being produced at lower temperatures (between 100 and 140 °C) than HMA [4]. Warm Mix Asphalt (WMA) emerged in Europe as a response to the need for a bituminous mixture that offered energy savings while maintaining the performance of hot bituminous mixtures. Some researchers have reported potential energy savings of about 30% [5]. Silva *et al.* [6] and Newcomb [7] reported that WMA could reduce CO2 emissions by 46%. Blankendaal *et al.* [8] evaluated the environmental performance of WMA using life cycle assessment (LCA) and reported a 33% reduction in negative impact.

Other advantages of warm mix asphalt include reduced compaction effort, quicker turnover to traffic, and better working conditions due to the absence of harmful gases and reduced asphalt temperature [9]. The mechanical performance of WMA has also been studied. Xie *et al.* [10] compared the mechanical impact of several types of WMA additives in the mixture; Sasobit, Rediset, and Evotherm were employed, with Evorthem reporting the lowest tensile strength. On the other hand,, the use of WMA additives in manufacturing modified asphalt mixtures with crumb rubber or other polymers has been mentioned. It was found that crumb rubber WMA had higher tensile strength, better moisture damage resistance, and fatigue performance than HMA incorporating crumb rubber [11]. Other authors mention a reduction between 20 and 30 Celsius degrees without affecting the mechanical properties of the mixture [12].

From the point of view of aging, WMA presents better short-term oxidation of the asphalt binder due to the lower temperatures in the manufacturing, extension and compaction processes, which can positively impact fatigue resistance and cracking at low temperatures [13]–[15].

There are different methods to produce WMA, and it can be produced by adding organic materials, chemical additives, and foaming the asphalt [16], [17]. WMA additives reduce the viscosity of the binder to facilitate mixing with the aggregates, coating them better and improving their mixing process at lower temperatures.

The main objective of this research is to evaluate the effects of incorporating two types of additives when preparing Warm Mix Asphalt (WMA), whose base is an asphalt binder with a 60-70 penetration degree. The two commercially available additives were dosed gravimetrically at 2.00% and 3.00% concerning the binder weight. The inclusion effects analysis considers two aspects. The first is on the variations in the asphalt binder (ductility, viscosity, penetration index, softening and flame point). The second is on the changes in the asphalt mixture (Marshal stability, flow, density, voids). The results are contrasted with the records of a typical Hot Mix Asphalt (HMA).

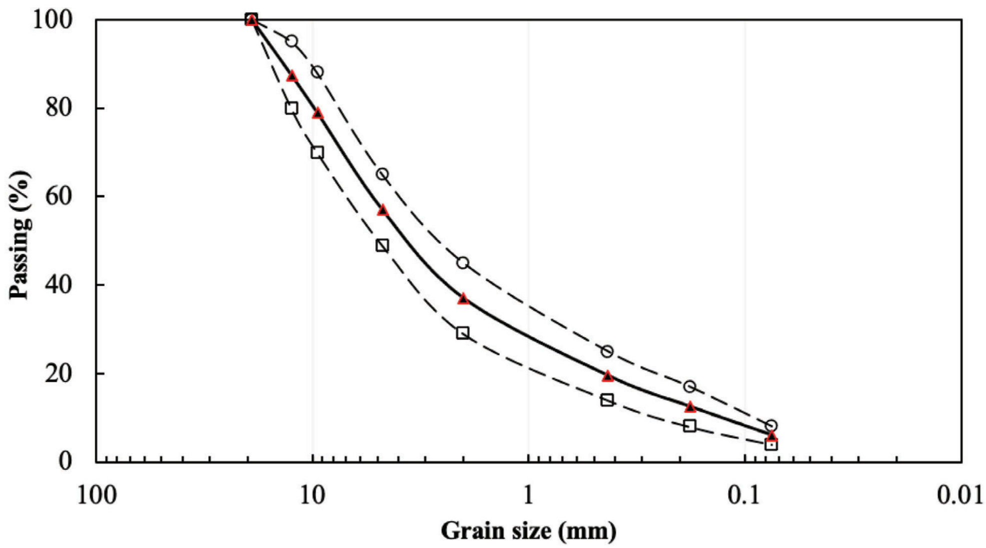
Materials and methods

The physical characteristics of 60-70 penetration grade binder and aggregates (coarse and fine) are presented in tables 1 and 2. The testing plan is reported in table 3 as a function of Binder content, Additive type and Additive content.

Materials

This study utilized conventional bitumen with a penetration grade of 60-70 to prepare specimens. Table 1 details the technical properties of the binder. Siliceous aggregates, milled from river stone materials, were used as coarse and fine fractions, as well as filler material. The grading curve employed in manufacturing the specimens followed the specifications of the National Roads Institute of Colombia (INVIAS, by its acronym in Spanish), with a nominal maximum aggregate size of 19 mm intended for use as a wearing course in the asphalt pavement structure. Table 2 and figure 1 illustrates the properties and gradation curves employed in preparing samples.

Figure 1. Gradation curve used in the preparation of specimens



Source: The authors.

Table 1. Specifications of 60-70 penetration grade binder

Property	unit	Standard	Value	Specification
Penetration	0.1 mm	INV - E 706	65	60 - 70
Softening point	°C	INV - E 712	48	48 - 54
Absolute viscosity 60°C	P	INV - E 716	1850	min 1500
Ductility	cm	INV - E 702	>110	min 100
Ignition point	°C	INV - E 709	274	min 230

Source: The authors.

Table 2. Basic properties of coarse and fine aggregates

Property	unit	Standard	Value	Specification
Coarse aggregate				
Specific gravity	g/cm^3	INV - E 223	2.44	-
Angeles abrasion	(%)	INV - E 218	25	< 25
Fine fraction				
Specific gravity	g/cm^3	INV - E 222	2.39	-
Sand equivalent	(%)	INV - E 133	81	> 50

Source: The authors.

As depicted in the figure, the black lines outline the upper and lower limits of the particle size distribution, while the grey line represents the gradation curve used for the sample preparation. Regarding the additives, two commercial WMA additives were used in this research. The first additive is a conventional surfactant additive composed of amines, referred to in this study as the "G" product. The other one, denoted as a "K" product in this research, has a solid granular appearance at 25°C. Its melting point of 147°C facilitates rapid addition and adhesion into the asphalt. It is employed to enhance the rheological properties of both conventional and polymer-modified binders. According to the providers, the K product decreases viscosity at temperatures above 110°C. The recommended dosage oscillates between 2.00% and 3.00% by weight of the bituminous binder.

Testing plan and methods

Firstly, the performance of the additives will be evaluated on the asphalt binder scale. Consequently, the additives were mixed with the asphalt binder using a rotational mixer at 300 revolutions for 10 minutes. The modifiers were added in 2.00 and 3.00% per cent by weight of asphalt mixture. In this phase, the mixing temperature was approximately 155°C. The rheological properties of the binder were evaluated through the ductility test (INV – E – 702 – 07), where a standard-size briquette of asphalt binder stretches to its failure breaking point. The penetration index was also defined to measure the consistency of the asphalt binder following the INV – E – 702 – 07 standard normative. The ring ball apparatus was also employed to determine the softening point of the bitumen (INV – E – 702 – 07). The flashpoint was calculated through INV – E – 709 – 07. Finally, the viscosity test was carried out to determine the mixing and compaction temperature of the asphalt mixture according to INV – E – 715 – 07.

In the second phase, the warm additives were assessed at the asphalt mixture scale through the density, voids test, Marshall Stability (MS), and flow test procedure (INV – E – 748 – 07). The concept of the design of experiments (DOE) was considered to deal with the experimental designs. This tool was very useful in determining the total number of mixtures produced. The complete factorial design was taken into consideration, and the control variables were the binder content (4.00%-6.00%), the type of additive, either G, K, or no additive (N), and its additive content (2.00%-3.00%). Four replicates per mixture design were performed to conduct the statistical analysis. Table 3 shows the set of 25 experimental designs considered for manufacturing and analysis.

Table 3. Pertinent information of the experimental designs assessed in the research

Number	Design	BC* (%)	AT**	AC***
1	4.00-N-0.00	4.00	-	0.00
2	4.50-N-0.00	4.50	-	0.00
3	5.00-N-0.00	5.00	-	0.00
4	5.50-N-0.00	5.50	-	0.00
5	6.00-N-0.00	6.00	-	0.00
6	4.00-G-2.00	4.00	G	2.00
7	4.50-G-2.00	4.50	G	2.00
8	5.00-G-2.00	5.00	G	2.00
9	5.50-G-2.00	5.50	G	2.00
10	6.00-G-2.00	6.00	G	2.00
11	4.00-G-3.00	4.00	G	3.00
12	4.50-G-3.00	4.50	G	3.00
13	5.00-G-3.00	5.00	G	3.00
14	5.50-G-3.00	5.50	G	3.00
15	6.00-G-3.00	6.00	G	3.00
16	4.00-K-2.00	4.00	K	2.00
17	4.50-K-2.00	4.50	K	2.00
18	5.00-K-2.00	5.00	K	2.00
19	5.50-K-2.00	5.50	K	2.00
20	6.00-K-2.00	6.00	K	2.00
21	4.00-K-3.00	4.00	K	3.00
22	4.50-K-3.00	4.50	K	3.00
23	5.00-K-3.00	5.00	K	3.00
24	5.50-K-3.00	5.50	K	3.00
25	6.00-K-3.00	6.00	K	3.00

Note: * Binder content. ** Additive type *** Additive content
Source: The authors.

Initially, 1200 g of dry, cleaned, and blended aggregates were initially measured for manufacturing each sample. The mixed aggregates were heated and thoroughly mixed. Then, the heated bitumen with the additive was added to the aggregates mix until a homogeneous mixture was achieved. The mixing and compaction temperature depended on the results obtained from the viscosity test. The compaction method was done through the Marshall Hammer by applying 75 blows per face.

Once the cylindrical specimens were manufactured, the bulk-specific gravity and air voids properties were determined by measuring their volumetric properties. Afterwards, the stability and flow tests were performed. The Marshall Stability corresponds to the maximum load to produce failure at the standard test temperature of 60°C. The load is applied at a constant strain of 50.8 mm/min. The Marshall flow is the strain at the failure point expressed in 0.01 inch or 0.25 mm units.

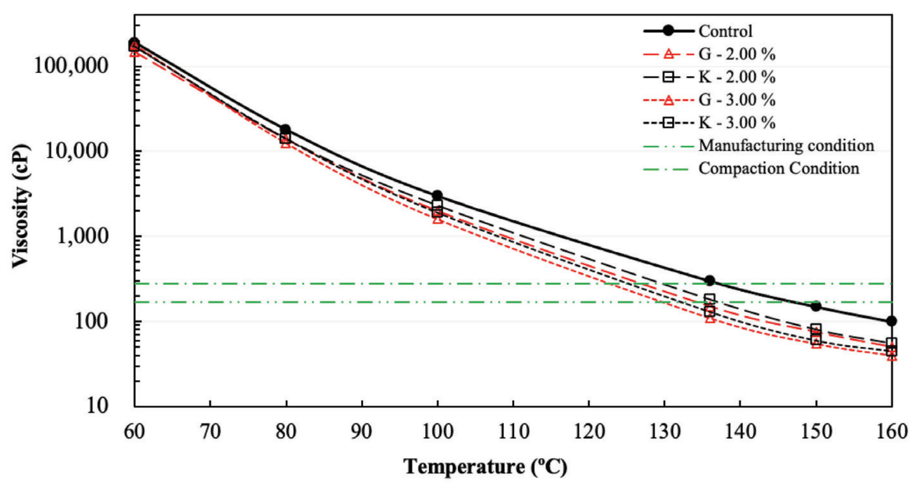
Results

The research results are presented in two lines. The first corresponds to the asphalt binder and the additive's effects. The second refers to Warm Mix Asphalt and their Bulk specific gravity, VMA, air voids, VFA, Marshall stability and flow value.

Asphalt binder

Table 4 shows the effects of WMA additives on the characterization properties of the bituminous binder. According to the results, the penetration value slightly increased with adding the "G" product, while it remained almost constant with adding the "K" additive. In the same way, the WMA modified with additives increased the softening point, ductility, and flash point properties. Although it was expected that with these modifiers, the viscosity was reduced and workability was improved, at these temperatures, the softening point tended to be higher because the microparticles tend to stiffen the bitumen at these temperatures [18]. This phenomenon is clearly observed in figure 2. Viscosity is an indicator of the resistance to flow and its internal friction. The results show that the modified binders' viscosity is lower than the control binder as the temperature increases. Waxes have melting points inferior to the bituminous binder, which can become scattered during mixing. As the wax content increased, the viscosity decreased for higher temperature ranges. This phenomenon was observed equally in both additives.

Figure 2. Viscosity results of asphalt binder



Source: The authors.

Table 4. Effects of WMA additives to characterization properties of asphalt binder

Binder property	Control value	G - 2.00%	G - 3.00%	K - 2.00%	K - 3.00%
Penetration [0.1 mm]	65	67	68	65	66
Softening point °C	48	48.2	49.8	49.5	49
Ductility [cm]	140	142	144	145	144.6
Flash point [°C]	274	280	278	282	279

Source: The authors.

Based on the results of the viscosity curve, it was possible to determine the manufacturing and compaction temperatures of the bituminous mixtures. The manufacturing temperature criterion yielded a viscosity value of 170 cP. The compaction temperature was obtained for a value of 280 cP. Consequently, the range of manufacturing and compaction temperatures can be observed in table 5.

Table 5. Manufacturing and compaction temperatures obtained from viscosity test

Temperature / binder	Control value	G - 2.00%	G - 3.00%	K - 2.00%	K - 3.00%
Manufacturing [°C]	146 - 154	132 - 135	126 - 130	132 - 137	128 - 131
Compaction [°C]	135 - 141	125 - 129	121 - 124	127 - 129	121 - 124

Source: The authors.

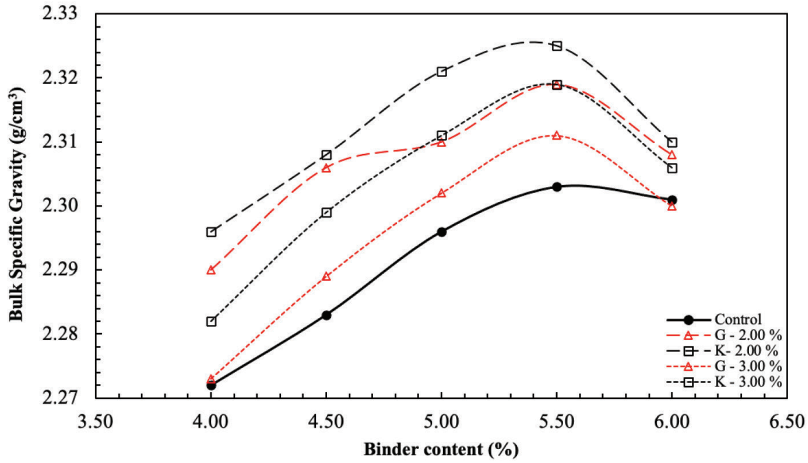
According to the results, the incorporation of either additives reduced the manufacturing and compaction temperatures of the mixture. Both admixtures functioned effectively, yielding quite similar values. Additionally, in both cases, a higher additive content led to a more significant reduction in temperature. This temperature reduction results in decreased energy consumption, greenhouse gas emissions, and a cooler working environment for asphalt workers [18].

Warm Mix Asphalt WMA

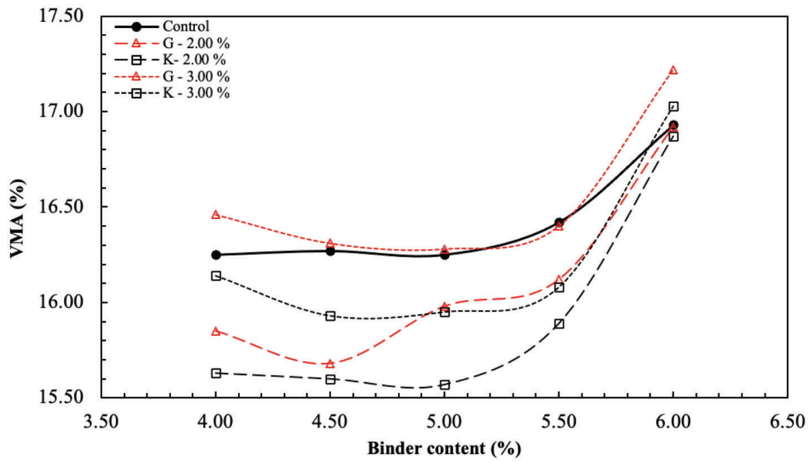
In compliance with Colombian regulations for designing dense-graded asphalt mixtures, bulk specific gravity, air voids, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), Marshall stability, and flow value are the main parameters used for quality control. Figure 3 displays the results regarding bulk density and volumetric properties. The black dotted lines indicate the limits set by Colombian regulations for high traffic levels.

Figure 3. Bulk Specific Gravity and volumetric properties of the mixtures

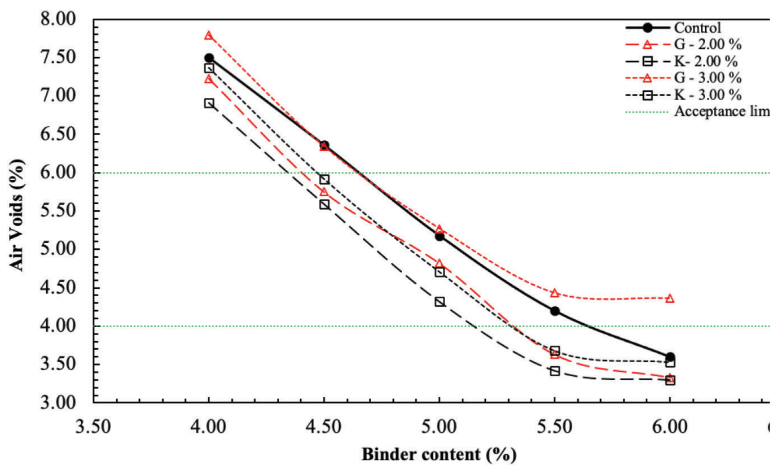
(a)



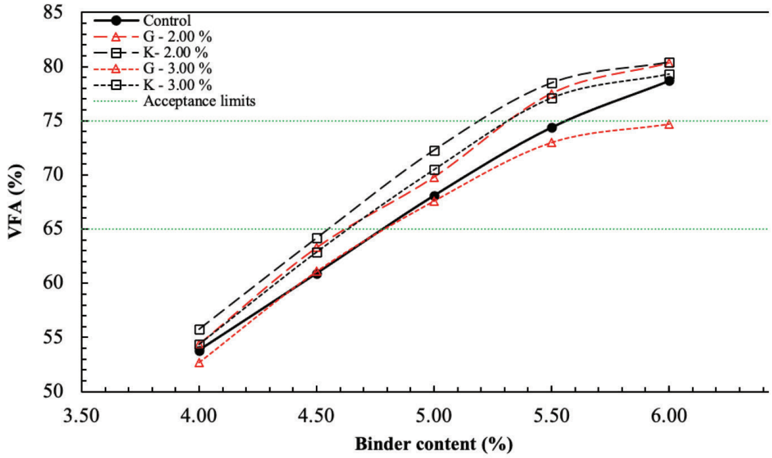
(b)



(c)



(d)



Source: The authors.
Note: (a) bulk specific gravity; (b) Voids in the mineral aggregate; (c) air voids; (d) voids filled with asphalt.

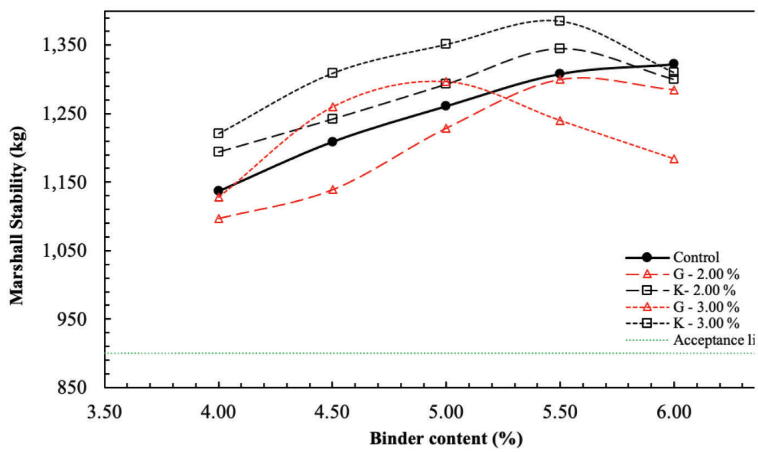
As depicted in figure 3a, the additives increased the bulk density of the mixture for the different bitumen contents. Regarding the VMA property, all mixes exhibited values greater than 15, the minimum suggested by Colombian norms for the wearing course. Concerning air voids property, both additives led to a reduction as binder content increased, as observed in figure 3c. The air voids ranged between 4.00 and 6.00% over a wide range of binder content, meeting the requirement of Colombian norms. Finally, VFA represents the voids in the mineral aggregate framework filled with bitumen. Consequently, the addition of the "K" product showed higher values than the control mixture, while in the case of "G" product, the increment in this property was less noticeable.

The Marshall Stability and flow value for the mixes were calculated, as shown in figure 4. The MS is a good indicator of the mixture's durability, while the flow indicates the asphalt mixture's flexibility, plasticity, and workability. Higher MS values were obtained with additive K at 3.00%, followed by the same additive at 2.00% by weight of asphalt binder. All mixes exhibited MS values greater than 900 kg, the minimum recommended in the Colombian specifications. Regarding flow value, the results suggest that the flow increases as the additive is added. The control mix had admissible flow values for the entire range of bitumen increments.

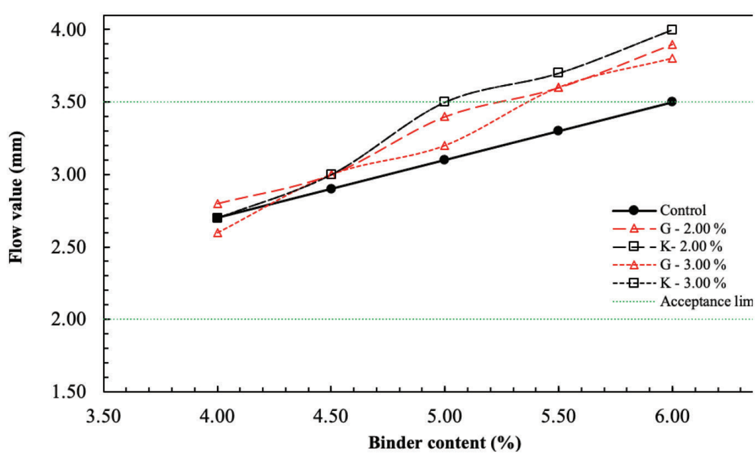
On the other hand, in the WMA, the flow tended to be higher than 3.50 mm for bitumen contents between 5.00 and 5.50 %. This aspect is a clear indicator that warm mixes can contribute to the workability of the mix by allowing it to flow better. It is worth mentioning that mixes with significant stability and low flow value are not desirable since they are prone to developing cracks due to heavy moving loads.

Figure 4. Evaluation of mechanical parameters

(a)



(b)



Source: The authors.
Note: (a) Marshall Stability; (b) Flow value.

The optimal binder content (OBC) for the five mixtures was calculated based on the average value of the following four criteria. i) The binder content (BC) associated with the maximum stability (fig. 4a), ii) The (BC) related to the maximum bulk density (fig. 3a), iii) The average value of (BC) with which "air voids" range between 4.00% and 6.00% (fig. 3c), iv) The average value of (BC) with which "voids filled with asphalt" range between 65.00% and 75.00% (fig. 3d). Consequently, the OBC of the mixtures is shown in table 6.

According to the results, the mixture without any additive displayed the highest OBC, followed by the mixes G – 3.00, K – 3.00, G – 2.00, and K – 2.00. Including warm additives can reduce binder content by 0.2 to 0.4%. More significant reductions were achieved with the "K" product instead of the "G" one. WMA with K additives notably increased the Marshall stability and bulk density and decreased the total air voids inside the mix.

Table 6. Optimum Binder Content OBC of the asphalt mixtures

Asphalt mixture	N - 0.00	G - 2.00	G - 3.00	K - 2.00	K - 3.00
OBC (%)	5.50	5.20	5.30	5.10	5.20

Source: The authors.

Conclusions

This study assessed the impact of two WMA additives on the characteristics of asphalt binder and asphalt mixtures. The "G" and "K" products were dosed by 2.00 and 3.00% by weight of asphalt binder. Based on the laboratory tests, the following conclusions can be drawn:

Concerning binder characteristics, minimum changes were observed in penetration and softening point, ductility, and flash point. The impact of additives was notably noticed on the viscosity property of the asphalt binder. Both additives reduced the viscosity as the temperature in the mixture increased. The reduction in the manufacturing and compaction temperature leads to a decrease in energy consumption, greenhouse gas emissions, and a colder working environment for asphalt workers.

Concerning asphalt mixtures, incorporating additives tended to increase the bulk density, the voids filled with asphalt, and decrease the air voids inside the mix. Similarly, higher MS and lower flow number values were observed in WMA instead of the control mixture. Incorporating these additives can reduce the optimal bitumen content by between 0.2% and 0.4%.

References

[1] P. Kushwaha and A. S. Chauhan, "Pavement design and construction using warm mix asphalt: A bibliometric overview," Mater Today Proc, Mar. 2023, doi: 10.1016/j.matpr.2023.03.040.

[2] M. Sukhija and N. Saboo, "A comprehensive review of warm mix asphalt mixtures-laboratory to field," Constr Build Mater, vol. 274, p. 121781, Mar. 2021, doi: 10.1016/j.conbuildmat.2020.121781.

[3] M. J. Amirkhani, M. Fakhri, and A. Amirkhani, "Evaluating the use of different fillers and Kaowax additive in warm mix asphalt mixtures," Case Studies in Construction Materials, p. e02489, Dec. 2023, doi: 10.1016/j.cscm.2023.e02489.

[4] D. Vaitkus, A., A. Čygas, Laurinavičius, and Z. Perveneckas, "Analysis and Evaluation of Possibilities for the Use of Warm Mix Asphalt in Lithuania," The Baltic Journal of Road and Bridge Engineering, vol. 4, no. 2, pp. 80-86, 2009, doi: https://doi.org/10.3846/1822-427X.2009.4.80-86.

[5] G. Zhaoa and P. Guo, "Workability of Sasobit Warm Mixture Asphalt," Procedia engineering, vol. 16, pp. 1230-1236, 2012. https://doi.org/10.1016/j.egypro.2012.01.196

[6] H. M. R. D. Silva, J. R. M. Oliveira, C. I. G. Ferreira, and P. A. A. Pereira, "Assessment of the Performance of Warm Mix Asphalts in Road Pavements," International Journal of Pavement Research and Technology, vol. 3, no. 3, pp. 119-127, 2010.

[7] D. Newcomb, "Warm mix: the wave of the future?," HMAT: Hot Mix Asphalt Technology, vol. 10, no.4

[8] T. Blankendaal, P. Schuur, and H. Voordijk, "Reducing the Environmental Impact of Concrete and Asphalt: A Scenario Approach," Journal of Cleaner Production, vol. 66, pp. 27-36, 2014, doi: https://doi.org/10.1016/j.jclepro.2013.10.012.

[9] Y. Babangida Attahiru, A. Mohamed, A. Eltwati, A. A. Burga, A. Ibrahim, and A. M. Nabade, "Effect of waste cooking oil on warm mix asphalt block pavement - A comprehensive review," Physics and Chemistry of the Earth, Parts A/B/C, vol. 129, p. 103310, Feb. 2023, doi: 10.1016/j.pce.2022.103310.

[10] Z. A. Xie, W. B. Fan, L. B. Wang, and J. Shen, "The Effectiviness of Warm Mix Asphalt (WMA) Additives Affected by the Type of Aggregate and Binder," International Journal of Pavement Research and Technology, vol. 6, no. 5, pp. 554-561, 2013.

[11] X. Yang *et al*., "Environmental and Mechanical Performance of Crumb Rubber Modified Warm Mix Asphalt Using Evotherm," Journal of Cleaner Production, vol. 159, pp. 346-358, 2017, doi: https://doi.org/10.1016/j.jclepro.2017.04.168.

[12] X. Wang, H., P. Liu, Apostolidis, and T. Scarpas, "Review of Warm Mix Rubberized Asphalt Concrete: Towards a Sustainable Paving Technology," Journal of Cleaner Production, vol. 177, pp. 302-314, 2018, doi: https://doi.org/10.1016/j.jclepro.2017.12.245.

[13] C. Akisetty, F. Xiao, T. Gandhi, and S. Amirkhanian, "Estimating Correlations between Rheological and Engineering Properties of Rubberized Asphalt Concrete Mixtures Containing Warm Mix Asphalt Additive," Constr Build Mater, vol. 25, no. 2, pp. 950-956, 2011, doi: https://doi.org/10.1016/j.conbuildmat.2010.06.087.

[14] H. Rondón and F. Reyes, Pavimentos, Materiales, Construcción y Diseño. Bogotá. Colombia., 2015.

[15] V. Kumar and E. Coleri, "Effects of finer gradation, temperature, warm mix additives, and compaction methods on density and performance of asphalt

mixtures," Constr Build Mater, vol. 394, p. 132226, Aug. 2023, doi: 10.1016/j.conbuildmat.2023.132226.

[16] A. M. S. Maidanova, S. N. Baranov, and N. V. Ivanov, "Influence of Natural Additives and Those Synthesized by the Fischer-Tropsch Method on the Properties of Petroleum Bitumen and Quality of Floated Asphalt," Coke and Chemistry, vol. 54, no. 1, pp. 26-31, 2011.https://doi.org/10.3103/S1068364X11010066

[17] M. R. Mohd Hasan *et al.*, "Effects of diluted methanol and water as foaming agents on the performance of latex foamed warm asphalt mixtures," Journal of Traffic and Transportation Engineering (English Edition), vol. 10, no. 3, pp. 413-426, Jun. 2023, doi: 10.1016/j.jtte.2021.07.007.

[18] P. Caputo *et al.*, "The Role of Additives in Warm Mix Asphalt Technology: An Insight into Their Mechanisms of Improving an Emerging Technology," Nanomaterials, vol. 10, no. 6, pp. 1-17, 2020, doi: https://doi.org/10.3390/nano10061202.