Journal of Engineering and Sustainable Development
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
https://doi.org/10.31272/jeasd.28.1.7

Vol. 28, No. 01, January 2024
ISSN 2520-0917

Original Research

# ASPHALT BINDERS EMPLOY VARIOUS ORGANIC ADDITIVES: PHYSICAL AND RHEOLOGICAL QUALITIES

Omar Adel Ismael*[1], Siham Idan Salih[2]

[1,2]*Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq*
[1] https://orcid.org/0009-0008-8318-6205
[2] https://orcid.org/0000-0002-1901-1530

***Received 04/07/2022*** ***Revised 17/01/2023*** ***Accepted 01/12/2023***

**Abstract:** Several studies aim to reduce surface temperatures and improve the performance of hot mix asphalt. These studies have occurred to reduce the global warming phenomena and economic concerns. We're researching how organic materials affect the viscosity of modified asphalt. Asphaltan A, Asphaltan B, Asphaltan C, and T-grade are organic additives. temperatures with the asphalt binder were employed in the current study. These organic additives were used to improve the characteristics of hot-mix asphalt. In addition, it increases the durability, and lifespan of pavement and reduces mixing and compaction temperatures. A penetration grade bitumen of 40/50 was used in this study. Then, pure bitumen was added to the organic additives to modify binders containing varying concentrations of each additive. Physical properties were performance at different levels of additives. In the research, conventional bitumen/asphalt should be adjusted due to climate conditions, strong traffic loads, and growing axial loads. As a result, asphalt mixtures comprehending bitumen with a high penetration index are less prone to low-temperature cracking and irreversible deformation. Traditional asphalt studies found that bitumen samples with the softening point of warm mix asphalt additives were greater rate, and were less susceptible to temperature changes. The introduction of organic compounds increased the penetration and softening point of the asphalt substantially. This indicated that the stiffness and thermal expansion of the binder had gotten better.

***Keywords:*** *Organic additives; warm mix asphalt; asphaltan A; asphaltan B; asphaltan C; T-grade temperature*

## 1. Introduction

The traditional Hot Mix Asphalt is used in the majority of field road systems in different Countries (HMA). The attention to utilizing WMA for pavements its different advantages over conventional HMA. The two most frequently mentioned benefits are lower fuel costs and lower hazardous emissions. Fuel savings are mentioned from some technologies reporting possible economies of lower mixture production temperatures, reduced air pollution , Carbon dioxide (CO2), and Nitrogen oxide (NOX). Sulfur dioxide (SO2), Carbon Monoxide (CO): Warm Mix Asphalt In recent decades, WAM technologies have garnered interest in Europe and the United States, including Australia and the United States of America.) [1]. In addition, the influence of the thermal expansion factor in terms of stress intensity factor, and the stress states within the asphalt concrete pavement influence fracture propagation [2]. Asphalt binders are obtained

**Corresponding Author:* edma029@uomustansiriyah.edu.iq

Work of This Research is Licensed under CC BY

from crudes, which are the most important cement in road surface mixtures around the world [3]. WMA technologies aim to achieve needed durability that is comparable to better than Pavement structures. The world's most commonly used WMA production technologies in Europe (Aspha-Min®, WAM-Foam®, and Low-Energy Asphalt®) are all patented technology mechanisms that are defined further down. In South Africa, a fourth proprietary product (Sasobit®) was created. Asphaltan B is another produced good that is currently undergoing little research and is used in Europe [3, 4]. At a given temperature, all of these technologies enable the creation of WMA by decreasing the viscosity and/or increasing the volume of the asphalt mix [5].

Jenkins et al. [6] proposed a new method for treating foamed bitumen that was half-warm. They looked into the ideas and advantages of heating a diverse range of aggregates to temperatures above surrounding air but below 100°C before applying foamed bitumen.

Asphalt binders are complex materials due to their pattern of a wide range of organic molecules [7]. At temperatures above their softening point, organic additives reduce heavy crude viscosity [8]. Yao. et al [7] explain that it is an intricate mixture made up of many hydrocarbons with various molecular weights. Consequently, they could be used to lower asphalt mixture manufacturing temperatures. In addition, Pereira, et al. [9] stated chemical agents, on the other hand, behave as an emulsifier, reducing the frictional forces between the binder and the aggregate, which recovers the covering and lowers manufacturing temperatures. As a result of fuel burning fossil fuels, warming is now one of the world's most pressing issues since the early twentieth Button, [9]. Methods using surfactants, organic additives, foam asphalt, and rod surface mixtures are indeed the four major types of warm-mix asphalt. techniques[4,10].At temperatures above their melting point, organic additives reduce asphaltic viscosity, they can also be used to lower the temperature of asphalt manufacturing[11].

To achieve this goal, with the above, WMA technologies modify binder characteristics such as viscosity or interfacial tension. just about any situation, the lower blending temperatures have raised questions about the mix's performance. In this vein, it is assumed that the WMA mixtures will be thoroughly evaluated and characterized to ensure adequate performance [12,14]. Warm-mix asphalt technology includes the organic additive technique as a major area. It really can decrease viscosity and also has a noticeable impact on asphalt effectiveness, particularly the concept or phenomenon at elevated heat.

## 2. Potential Advantages

Warm Mix Asphalt (WMA) is an innovation that lowers the temperature of manufacturing and compaction.

Environmentally. Because the temperature is essentially zero and the air quality is poor, steam and greenhouse present in the atmosphere (resulting in less Carbon dioxide and other carbon pollution) are reduced [13, 12,15].

Production - The ageing process of the bituminous mix during the manufacturing and paving processes is closely monitored, which improves the pavement's reparability.

Paving - By lowering bitumen viscosity at paving temperature, compaction and workability are improved [16]. The long-term distance increases as the construction season progresses. As a result of a low starting temperature, the pavement cooling time is reduced. Because emissions, odour, and fumes are reduced, it is convincing to the public in the vicinity of work and production sites deviation.

## 3. Laboratory Works and Materials

The present study is shown in Fig.1, this figure describes the work plan for this study, materials such as additives with percentages, and the work plan.

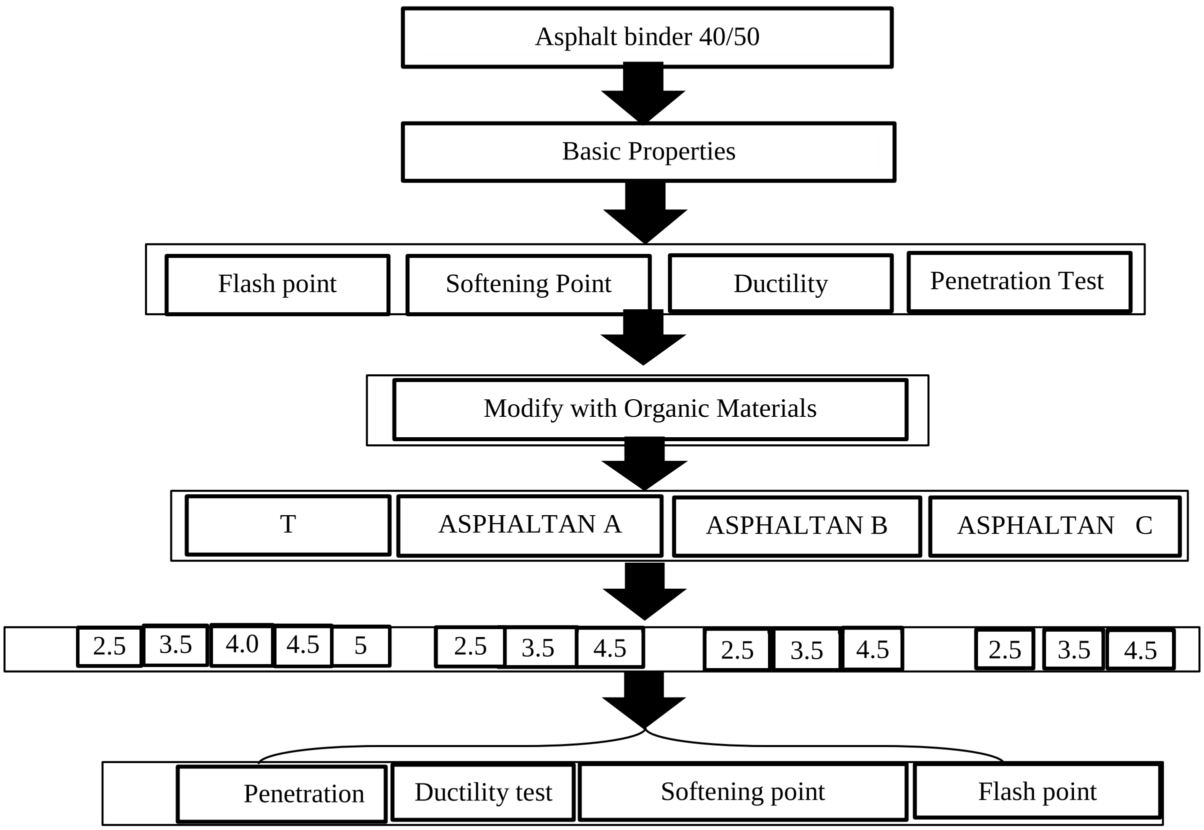


**Figure 1**. Workplan for the current study

### 3.1 Materials

*3.1.1 Base Binder and Tests*

The major characteristics of a base binder (BB) with a grade 40/50 penetration can be found in Table 1. This binder was obtained from the Al-Durah refinery in southern Baghdad. Specimens were subjected in sample containers basically as specified and employed in a water bath for 1 to 1.5 hours well before the test at the specified temperature to measure penetration test as clear in standard pentation test.

**Table 1.** Properties of Base Bitumen

| Binder Tests | Result | Require | ASTM Design |
|---|---|---|---|
| Penetration, 0.1mm | 47 | 40-50 | D 5[24] |
| Ductility; cm | 133 | > 100cm | D113[18] |
| Softening Point, °C | 52 | 50-58; °C | D36[19] |
| Flashpoint, °C | 253 | > 230 °C | D92[20] |

The effect of the properties on the base binder of this study, 4 percent organic materials were used, these materials (T) grade temperature, ASPHALTAN A, ASPHALTAN B, ASPHALTAN C. The properties, however, of these additives as shown in Table (2).

**Table 2.** Lists the various WMA items that are commonly used, as well as their intake and decreased temperature ranges

| Product Company | Description | Additive/Dosage | Production | temperature (or reduction ranges) |
|---|---|---|---|---|
| Asphaltan A | Romonta GmbH | Refined Montan wax with fatty acid amide | 2-3% by weight of bitumen | 20°C-30°C |
| Asphaltan B | Romonta GmbH | Refined Montan wax with fatty acid amide | 2-4% by bitumen weight | 20°C-30°C |
| Asphaltan C | Romonta GmbH | Refined Montan wax with fatty acid amide | 2-4% by bitumen weight | 30°9C-40°C |
| T (temperature) | Limited liability company “SPK Resource “Moscow | | 3.5-5% by bitumen weight | |

Bennett et al. [17] stated that Asphalt binders' ageing qualities are often studied in laboratory settings through the measurement of their physical and chemical characteristics (e.g., softening point, penetration, consistency, and complex modulus) before and after artificial ageing.

The Bitumen tests were applied to calculate the properties of this original bitumen and how additives affect them. As a result, Tests for ductility, softening point, ring and ball technique, and penetration were conducted at ambient temperature. Furthermore, each case's penetration index was considered. The standard penetration at 25 °C[18-22], which proves bitumen viscosity in the hard form, is the most important laboratory test for determining. The Bitumen tests were applied to calculate the properties of this original bitumen and how additives affect them. As a result, penetration test, ductility, and softening point at ambient temperature were carried out [21].

*3.1.2 Penetration Index (PI) Calculation*

The penetration index is calculated under the assumption that bitumen has a penetration of 800 at the softening point of the Ring & Ball test (See Fig. 2). Pfeiffer and Van Doormaal [23] computed the penetration value for the bitumen viscosity at the softening point temperature.

By directly measuring the ASTM softening point temperature and linearly calculating the logarithm of penetrating with temperature, they found that many, but not all, bituminous had a penetration of 800 mm.

In addition, [24] discovered that the temperature rise was roughly linear at any location on the asphalt's surface. Furthermore, direct tests have demonstrated that at their softening point temperature (13 000 poise), the bulk of bitumen has a viscosity of approximately 1300 Pa [24]. For the same reason, the PI can be used because it is a clear indicator: (1) The values of A and the PI can be computed using penetration observations at two distinct temperatures, T1 and T2.

Plotting the logarithm (base 10) of penetration, log pen, against temperature, T, as shown in (2), yields a straight line. In the case when A is a constant and K is not, the temperature sensitivity is represented by the slope of the line in Fig. 2. The fact that A's value varies between about 0.015 and 0.060 suggests.

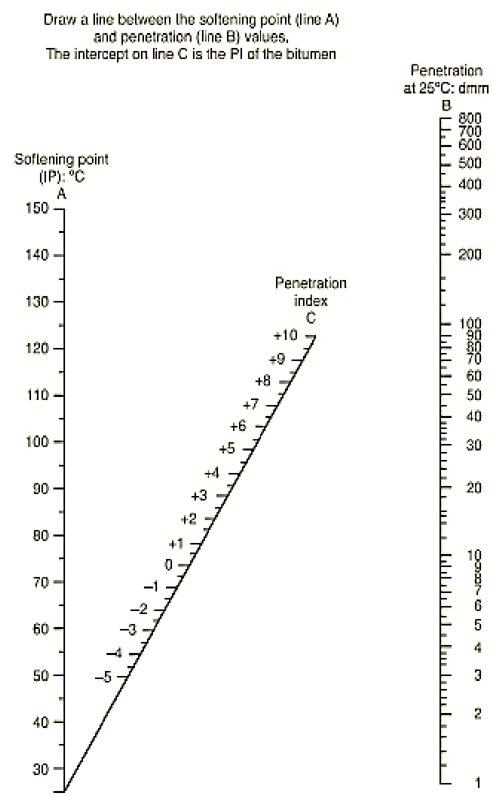


**Figure 2**. Using a nomograph, the softening point temperature and penetration value at 25 degrees were found to be the bitumen penetration index.[25].

$$\log \mathrm{P} = \mathrm{At} + \mathrm{K} \qquad (1)$$

Where

A = The temperature susceptibility,

P = Penetration at temperature, and

T K = Constant.

The most crucial laboratory test for figuring out bitumen type is the normal penetration at ambient temperature (25 °C), which demonstrates bitumen viscosity in the hard state. The bitumen gets softer with a higher penetration value.

The greatest used experimental technique for determining bitumen flexibility is the point at which it softens (Ring and Ball) approach. Plasticity is the capacity of persistent materials to change shape over time without attempting to shatter while under stress.

The heat sensitivities of a group are shown by the penetration index (PI). The softening point and a known penetrate standard value of ambient temperature are used in the calculation.

The PI can be estimated using the nomograph as seen in Fig. 2 built on the penetration at 25 C and the softening point temperature.

The more quickly the binder's firmness changes with temperature, the lower the penetration index (PI). As demonstrated below, a penetrate index is computed using (2).

$$PI = \frac{20(1-25A)}{1+50A} \qquad (2)$$

Where

PI: Penetration Index

A = The temperature susceptibility.

### *3.1.3 Organic Additives Materials*

A Romonta GmbH company Amsdorf, Germany supplied the organic WMA additive used in this study. These natural WMA additives are an aliphatic polyester polymethylene hydrocarbon with a transition temperature of roughly 120°C [12], as shown in Table 2. At temperatures above 140°C, it is highly soluble in bitumen.

The bitumen blends that were tested were virgin bitumen, bitumen with percent synthesized Asphaltan(A) by bitumen weight +2.5,3.5, 4.5, percent synthesized Asphaltan (B) by bitumen weight +2.5,3.5, 4.5, percent synthesized Asphaltan (C) by bitumen weight +2.5,3.5, 4.5, and percent synthesized Grade (temperature) by bitumen weight 2.5,3.5,4,4.5,5, Except for T (Temperature) liquid form, these are usually supplied in pellets or flakes, as shown in Fig 3.

- **T grade**

This material was obtained from the Limited liability company "SPK Resource" Аль-Карагули М.М./, in label number be found in Table 2.

- **Asphaltan A**

This specifications material is Pastilles 1 – 4 mm: at least 95 %, a field of application of quantity use is 2-3% by weight of bitumen content this shown in Fig.3(a).

- **Asphaltan B**

0-2mm Pastille of delivery specifications, Quantities of use:2-3 % by weight of bitumen. (Related to the bitumen content) as shown in Fig 3(b).

- **Asphaltan C**

Delivery specifications are Pastilles 0 – 4 mm: at least 95 %, quantities of use: 2 - 3 % by weight of bitumen. (Related to the bitumen content) this shown in Fig. 3(c).


(a) Asphaltan A, (b) Asphaltan B, (c) Asphaltan C

**Figure 3.** Scheme of WMA additives classifications

## 4. Results and Discussions

### 4.1 Softening Point Results

Table 1 shows the traditional properties of bitumen tested when a bitumen original without additives was studied. However, the different additives and percentages are represented from Table 3 to Table 6. These additives are available as Asphaltan T (grade temperature), Asphaltan A, Asphaltan B, and Asphaltan C. Fig. 4-d shows the softening point and penetration test for T (grade Temperature) additive in (2.5,3.5,4,4.5, and 5) percent by weight of bitumen investigated, as an example. In [26], a similar chart was recently disclosed.

**Table 3.** Properties of bitumen with different Percent of T grade (temperature)

| Binder Tests | Origin asphalt | Percent of additive T | | | | | Require | ASTM Designation |
|---|---|---|---|---|---|---|---|---|
| | | 2.5 | 3.5 | 4 | 4.5 | 5 | | |
| Penetration, 0.1mm | 47 | 44.5 | 60 | 70 | 78 | 99 | 40-50 | D5 |
| Ductility, cm | 133 | 147 | 141 | 145 | 145 | 165 | > 100cm | D113 |
| Softening Point; °C | 52 | 52 | 41.7 | 44.2 | 43.5 | 44 | 50-58; °C | D36 |
| Flashpoint, °C | 253 | 233 | 268 | 269 | 270 | >273°C | > 230 °C | D92 |

**Table 4.** Properties of bitumen with different Percent of Asphaltan A

| Binder Tests | origin asphalt | Percent of additive Asphaltan A | | | Requirements | ASTM Designation |
|---|---|---|---|---|---|---|
| | | 2.5 | 3.5 | 4.5 | | |
| Penetratio0.1mm | 47 | 50 | 44 | 43 | 40-50 | D 5 |
| Ductility, cm | 133 | 137 | 105 | 100 | > 100cm | D.113 |
| Softening Point, °C | 52 | 70.4 | 78 | 80 | 50-58; °C | D;36 |
| Flashpoint, °C | 253 | 267 | 268 | 270 | > 230 °C | D92 |

**Table 5.** Properties of bitumen with different Percent of Asphaltan B

| Binder Tests | Origin asphalt | Percent of additive Asphaltan B | | | Requirements | ASTM Designation |
|---|---|---|---|---|---|---|
| | | 2.5 | 3.5 | 4.5 | | |
| Penetrant, 0.1mm | 47 | 43 | 40 | 35 | 40-50 | D 5 |
| Ductility, cm | 133 | 125 | 110 | 115 | > 100cm | D.113 |
| Softening Point, °C | 52 | 66.2 | 76.5 | 70.5 | 50-58; °C | D;36 |
| Flashpoint, °C | 253 | 267 | 269 | 271 | > 230 °C | D92 |

**Table 6**. Properties of bitumen with different Percent of Asphaltan C

| Binder Tests | Origin asphalt | Percent of additive Asphaltan C | | | Requirements | ASTM Designation |
|---|---|---|---|---|---|---|
| | | 2.5 | 3.5 | 4.5 | | |
| Penetrant, 0.1mm | 47 | 47 | 44 | 38 | 40-50 | D 5 |
| Ductility, cm | 133 | 135 | 130 | 120 | > 100cm | D.113 |
| Softening Point, °C | 52 | 55.1 | 53.2 | 60.1 | 50-58; °C | D;36 |
| Flashpoint, °C | 253 | 264 | 267 | 268 | > 230 °C | D92 |

The 52–44 degree range represented the softening point. Celsius and the penetrate test from 44.5 to 99 mm in Fig. 4-d. The concentration data, however, show that practically all of the samples have lower T (grade Temperature) additive values. It illustrates how the penetration rose as more additive T was applied to the bitumen. Differences have been signified in Fig.4, as a sample test. A comparable Fig. 4-d resulted from these additives as a decrease in penetrating and an increase in softening point. Increased softening point is beneficial because bitumen with a greater softening point may be less prone to permanent deformation (rutting) [27-28].

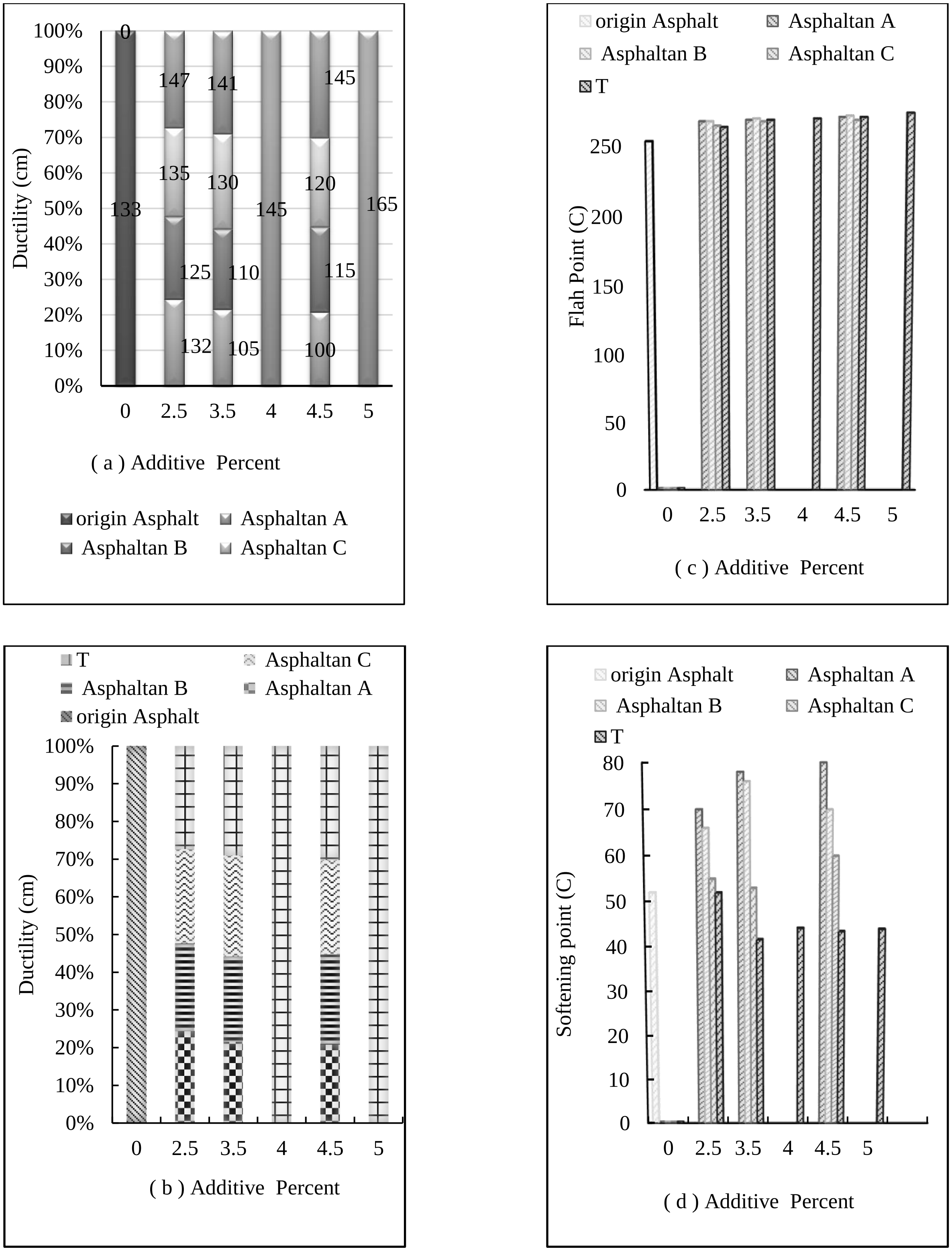


**Figure 4**. Penetration test, Ductility test, flash point, and Softening point for plot of different percent organic additives Asphaltan A, Asphaltan B, Asphaltan C, T GRADE, and Origin asphalt.

### 4.2 Results of Penetration Index (PI)

Organic (applicable to all contents) WMA additions may begin to reduce the softening point of bitumen (as indicated by the penetration index-PI). Reduced PI value is shown in Fig. 5 greater temperature sensitivity. Table 7 shows that as the WMA additive level increases, all WMA samples display decreased temperature susceptibility than basic bitumen.

**Table 7**. Results of ductility ratio for asphalt Modified

| Percentage of additive | Asphaltan A | Asphaltan B | Asphaltan C | Asphaltan T |
|---|---|---|---|---|
| | Decreased ratio (%) | | | Increased ratio (%) |
| 2.5 | 0.75 | 6 | 1.5 | 11 |
| 3.5 | 21 | 17 | 2 | 6 |
| 4 | - | - | - | 9 |
| 4.5 | 25 | 13 | 10 | 9 |
| 5 | - | - | - | 24 |

Fig. 4 demonstrates that the bitumen sample has appropriate temperature sensitivity and specificity for PI values. Furthermore, the bitumen having organic additive exhibits the lowest temperature resistance of all additives, but only in certain ranges.

Natural additives could be used in areas with a wide range of climatic change because bitumen altered with different additives, such as Asphaltan A, Asphaltan B, Asphaltan C, and T temperature, maintains its physicochemical characteristics in optimal conditions while having a steadily increasing softening point. Asphalt mixtures with a greater PI bitumen are often more impervious to low-temperature crack propagation and elastic modulus [29].

Fig. 4-d depicts the effect of various T-grade (Temperature) concentrations on the softening point. When compared to the base bitumen, the addition of additives to asphalt penetration grade 40/50 slightly raises the softening point. The overall softening points

for the various concentrations of T-grade bituminous are in a limited set, indicating that T-grade temperature has very little influence on softening point rise. Overall, the reduced penetration value and rising softening value of T-grade modified bitumen indicate increased binder toughness and stiffness, which are beneficial in the fuel industry.

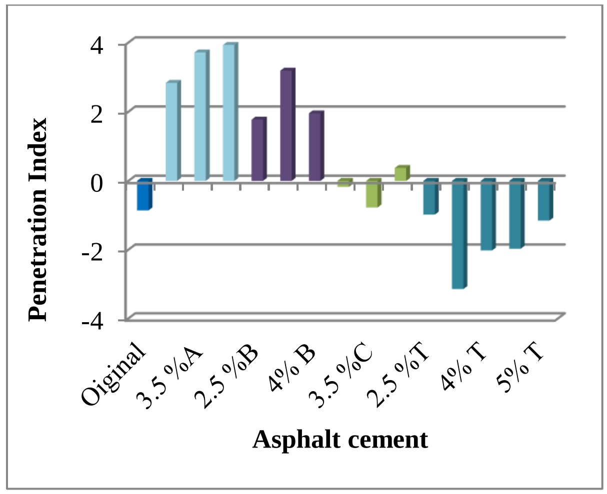


**Figure 5**. Penetration index of modified asphalt mixture

### 4.3 Results of the Ductility of Modified Binder

Fig. 6 shows the ductility test with different percent of additives, a ductility test provides a measure of the asphalt cement's tensile qualities as a measure of how far it can extend before fracturing. The values of ductility for the original and modified asphalt cement are shown in Figure. By comparing the results with the value of the original asphalt, it was found that the ductility of the substituted asphalt cement with Asphaltan A®, Asphaltan B®, and Asphaltan c® decreased as the proportion increased from 2.5% to 3.5% by the weight of the binder.

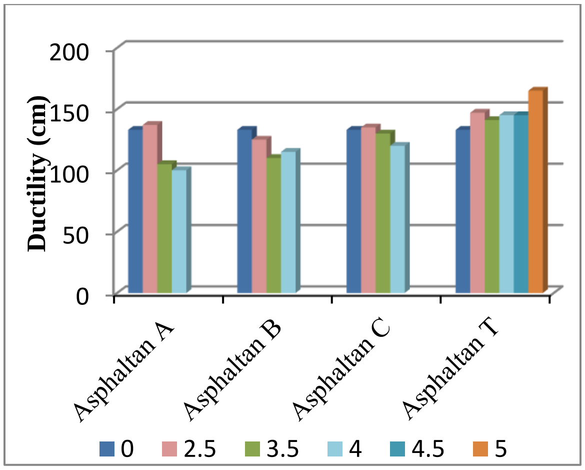


**Figure 6**. Relation between ductility with a different percent of additives.

## 5. Conclusions

Many significant findings of this study are as follows**:**

The results of this study showed that additional material is an essential component in understanding how rheological qualities in asphalt binders reduce viscosity. These additives include the Asphaltan A, B, C, and T grades.

According to the penetration index–PI, conventional asphalt testing showed that bitumen samples with WMA additions had a lower temperature susceptibility and a higher Softening point. Greater temperature sensitivity is indicated by a lower PI value. Asphalt mixtures comprising bitumen with an increased PI are less prone to experience persistent deformation and low-temperature cracking.

In conclusion, Asphaltan A, Asphaltan B, Asphaltan C, and T grades are excellent compounds being used as an additive in warm mix asphalt because they enhance the binder's rheological properties.

The bitumen additives have the ability to decrease bitumen viscosity at varying quantities without significantly altering the composition of the asphalt mixture.

The primary conclusions of the paper are as follows: The penetration and softening point of the asphalt were significantly increased by the addition of organic additives. This demonstrated that both the binder's thermal expansion and stiffness had improved. Rising ductility values were attributed to the addition of organic additive, with increments of 2.5% placing them higher than 3.5 and 4.5 percent.

**Acknowledgments**

The authors highly appreciated Mustansiriyah University, Highway and Transportation Engineering Department for supporting and accomplishing this work.

**Authors Contribution**

Siham Salih planned the research prearranged the tests, performed the experiments, and wrote the paper. Omer Adel organized the experiments. and wrote sections of the paper.

**Conflict of interest**

The authors declare that they have no conflicts of interest to report regarding the current paper.

**Abbreviations**

| | |
|---|---|
| WAM | Warm Asphalt Mixture |
| PI | Penetration Index |
| T | T (Temperature grade) |

**References.**

1. John D'Angelo, Eric H., John B., Gaylon B., Matthew C., Jack C., Thomas H., Mostafa J., Wayne J., Dave N., Brian P., Ron S., and Bruce Y. 2008. *Warm-mix asphalt: European practice*. , United States. Federal Highway

Administration. Office of International Programs.

2. Carnesale, A. and W. Chameides, 2011, *America's climate choices.* NRC/NAS USA Committee on America's Climate Choices https://www.pnas.org/doi/10.1073/pnas.1519212112

3. Alkaiss, Z.A. and S.E.S. Al-Maliky,2009 *Combined effect of wheel and thermal load conditions on stress distribution in flexible pavement.* Engineering and Technology Journal, University of Technology, Vol. 27, Issue 12: p. 2257-2267. https://doi.org/10.30684/etj.27.12.2

4. Gao, J., Yan, K., He, W., Yang, S., & You, ,2018. *High temperature performance of asphalt modified with Sasobit and Deurex.* Construction and Building Materials, Vol.164: p. 783-791.

https://doi.org/10.1016/j.conbuildmat.2017.12.164

5. Hurley, G.C. and B.D. Prowell, 2005, *Evaluation of Sasobit for use in warm mix asphalt.* NCAT report. Vol.5**,** Issue 6: p. 1-27.

[PDF] Evaluation of Sasobit® for Use in Warm Mix Asphalt | Semantic Scholar

6. Croteau, J.-M. and B. Tessier. 2008, *Warm Mix Asphalt Paving Technologies: a Road Builder's Perspective*. in *Annual Conference of the Transportation Association of Canada, Toronto*. DOI:10.1088/1757.

7. Yao, H., Liu, J., Xu, M., Bick, A., Xu, Q., & Zhang, J., 2021 *Generation and properties of the new asphalt binder model using molecular dynamics (MD).* Scientific Reports,. Vol.11, Issue 1. p. 1-15.

https://doi.org/10.1038/s41598-021-89339-5

8. Almeida-Costa, A. and A. Benta, 2016, *Economic and environmental impact study of warm mix asphalt compared to hot mix asphalt.* Journal of Cleaner Production, Vol.112: p. 2308-2317.

https://doi.org/10.1016/j.jclepro.2015.10.077

9. Pereira, R., Almeida-Costa, A., Duarte, C., & Benta, A. ., 2018. *Warm mix asphalt: Chemical additives' effects on bitumen properties and limestone aggregates mixture compactibility.* International Journal of Pavement Research and Technology. Vol.11, Issue 3: p. 285-299.

https://doi.org/10.1016/j.ijprt.2017.10.005

10.Button,J.W.,C.K.Estakhri, and A.J.2007, Wimsatt, *A synthesis of warm-mix asphalt..*

https://doi.org/10.1007/s10640-013-9664-9

11.Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., ... & Meinshausen, M, 2016, *Paris Agreement climate proposals need a boost to keep warming well below 2 C.* Nature, Vol. 534, Issue 7609: p. 631-639.

https://doi.org/10.1038/nature18307

12.Rashwan, M.H., 2012, *Characterization of Warm Mix Asphalt (WMA) performance in different asphalt applications*., Iowa State University.

https://doi.org/10.31274/ETD-180810-1335

13. Rubio, M. C., Martínez, G., Baena, L., & Moreno, F.,2012, *Warm mix asphalt: an overview.* Journal of Cleaner Production, Vol.24: p. 76-84.

https://doi.org/10.1016/j.jclepro.2011.11.053, 14.Abdulrahman, S., Hainin, M. R., Satar, M. K. I. M., Hassan, N. A., & Usman, A, 2019 *Rutting and moisture damage evaluation of warm mix asphalt incorporating POFA modified bitumen.* Int. J. Eng. Adv. Technol, Vol.9**,** Issue 1.

https://doi.org/10.35940/ijeat.A1052.109119

15.O'sullivan, K. and P. Wall, 2009, *The effects of warm mix asphalt additives on recycled asphalt pavement.* Worcester Polytechnic Institute.

https://doi.org/10.3311/PPci.8498

16. Zettler, R., 2006, *Warm mix stands up to its trials.* Better roads, Vol.76**,** Issue 2.

https://api.semanticscholar.org/CorpusID:107244262

17. Bennett, T., et al., 2010), *Assessment of workability and compatibility of warm-mix asphalt.* Transportation research record, Vol.2180, Issue 1: p. 36-47.

https://journals.sagepub.com/doi/10.3141/2180-05

18.Standards test for,A.S.T.M. and D.o.B. Materials1 2007, Dec. 1, ( United States).

ASTM D113-171: Standard Test Method or Ductility of Asphalt Materials (ihs.com)

19.Standards, A.B.o.A., 1993, *Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus.* D 36 – 86. Vol 04.02.

ASTM D36/86: Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus. (ihs.com)

20.Tester, C.O.C., *ASTM D-92* 2012. *Standard Test Method for Flash and Fire Points.* ASTM D-92 (2012).

ASTM D92 : Standard Test Method for Flash and Fire Points for Bitumen materiales (ihs.com)

21.Cong, P., Wang, J., Li, K., & Chen, S..,2012. *Physical and rheological properties of asphalt binders containing various antiaging agents.* Fuel, Vol.97: p. 678-684.

https://doi.org/10.1016/j.fuel.2012.02.028

22.ASTM, D., 2013, *Standard test method for penetration of bituminous materials.* USA, ASTM International,.

ASTM D5/D5M: Standard Test Method for Penetration of Bituminous Materials (ihs.com)

23.Pfeiffer, J.P. and P. Van Doormaal, 1936 *The rheological properties of asphaltic bitumens.* Journal of the Institute of Petroleum Technologists, Vol. 22: p. 414-440.

https://doi.org/10.1007/978-3-642-49337-9_105

24.Salih, S.I., A. Garcia, and J.N. Contreras, 2023, *Micro-Capsules And Induction Heating: Two Methods For Closing Cracks In Asphalt Porous Pavements*. Journal of Engineering and Sustainable Development, Vol. 27**,** Issue 4: p. 448-459.

https://doi.org/10.31272/jeasd.27.4.3

25.Heuckelom, W. 1973..*An improved method of characterizing asphaltic bitumens with the air of their mechanical properties*. in *Association of Asphalt Paving Technologists Proc.*

https://trid.trb.org/view/35221

26.Bitumen, S.,( 1990), *The Shell bitumen handbook.*: Shell Bitumen UK.

https://www.icevirtuallibrary.com/doi/book/10.1680/tsbh.58378

27. Ohinola, O.A., O.A. Felode, and G. Jonathan, (2012), *Softening point and Penetration Index of bitumen from parts of Southwestern Nigeria.* Nafta. Vol.63**,** (9-10): p. 324-327.

https://iopscience.iop.org/article/10.1088/1742-6596/1973/1/012233

28. Sengoz, B. and G. Isikyakar, *Short-term and long-term ageing behaviour of rubber modified asphalt paving mixture.* Journal of Hazardous Materials, 2008. Vol.150, Issue 2: p. 424-432.

https://doi.org/10.3141/1530-02

29. Liang, R.Y. and S. Lee, *Short-term and long-term ageing behaviour of rubber modified asphalt paving mixture.* Transportation research record, 1996, Vol.1530, Issue 1: p. 11-17. https://doi.org/10.1177/036119819615300102