Laboratory assessment of performance of WMA containing Sasobit

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Abstract. Over the time, comparing with the traditional hot mix asphaltic (HMA) mixture, the warm mix asphaltic (WMA) mixture has become extremely widespread in the construction projects of highways because the WMA mixture provides the possibility of manufacturing asphalt mixes at a lower temperature than the traditionally utilized HMA. Thus, it reduces energy consumption, decreases CO2 emissions and improves the quality of the environment. The goal of this research was to determine the impact of the Sasobit addition on the sensitivity of mixes to permanent deformation and moisture. Under the framework of this study, four percentages of Sasobit were added are 1.0, 2.0, 3.0, and 4.0 % to investigate the effect of increasing Sasobit content on the moisture and rutting resistance of asphalt mixtures. In summary, the rut of WMA, which was tested in the Hamburg Wheel Tracking Device (HWTD), was decreased as compared to the control HMA, while the rut depth was even lower at 1.0, 2.0, and 3.0 % than that of 4.0 % Sasobit. The moisture resistance was decreased (as compared to conventional HMA) by Sasobit addition, as shown by reducing the tensile strength ratios (TSR), but it was still higher than the minimum of 80%.

1. Introduction
The asphaltic industry studied the warm asphalt technique in recent years as a way of minimizing the production and placement temperature in asphaltic mixes. The WMA is an asphaltic mix that has been produced at minimizer temperatures in comparison to the traditional HMA mixture. In addition to reducing consumption of energy, carbon dioxide emissions, and asphalt deterioration, WMA technology extends the paving season and improves paving length for a safer working climate. Reducing the energy consumption helps in reducing project costs as a direct consequence of reducing the temperature of WMA manufacture [1, 2, 3, 4, 5]. Reductions in energy consumption ranged from 10.0 % to 30.0 % on average when the temperature of heating dropped from 150 °C to about 125 °C [6, 7]. Many WMA technologies are commonly used likes foaming, organic, and chemical technology. The Sasobit organic additive is a long chain aliphatic-hydrocarbon produced from the gasifications of coal. Sasobit melting temperature is approximately 100 °C to 105 °C [8, 9]. Warm mix asphaltic (WMA) is a set of techniques that enable asphaltic mixtures to be mixed and placed at reduced temperatures. This is achieved by reducing asphalt viscosity and full aggregate coating at a lower temperature [10]. When construction temperatures are obtained using an asphaltic mixture, volumetric
characteristics such as the asphalt cement film thickness, the temperature of construction for the WMA mixture containing Sasobit is 21°C lower than the traditional HMA [11].

A study shows that adding Sasobit to asphalt cement minimized the rut deepness of the mixtures [2]. The research investigated the characteristics of four types of warm asphaltic mixes. The findings showed that the values of the indirect tensile strength (IDT) and tensile strength ratio (TSR) of the specimens of WMA mixture were greater than the conventional HMA, while the WMA specimens showed the lowest permanent deformation with the Sasobit additive [12]. Some researchers assessed three various additives of WMA and deducted that all of the three techniques optimized the compatible of the asphaltic mix and produced minimizer air voids as a comparison to traditional HMA [11, 13, 14]. Another study illustrated that Sasobit significantly increased the resistant to rut depending on the test of repeated creep recovery [15]. The study showed that the TSR values in WMA mixture with Aspha-min and Sasobit additives were less than 85 percent but increased above 85 percent with the addition of 1.0 percent of the hydrated lime [15]. A researcher conducted a study to investigate the impact of sasobit addition on moisture sensitivity and permanent deformation of the asphaltic mixtures. The outcomes exhibited that the rut depth of the WMA decreased slightly compared to the control HMA so that the rut depth was reduced by increasing the sasobit content. A small drop in the moisture resistance (compared to the control hot mixture) is observed with the addition of Sasobit, as shown by the reduction of tensile strength ratio (TSR) [16].

There are many local studies conducted in this field, including a study that evaluated Marshall stability, compressive strength, Marshall quotient, index of retained strength, and rut resistant test of styrene-butadiene-styrene asphalt mixtures containing zeolite and sasobit additives. This study showed the SBS-HMA with zeolite had higher Marshall stability; was more resistant to rutting, and more moisture-resistant than the SBS-HMA with sasobit [17]. Another study has presented the outcomes of laboratory testing carried out to assess the characteristics and performance of WMA. The WMA has been prepared from two asphalt binder grades and one aggregate source with two types of additives (Sasobit and Aspha-min). In addition to the Sasobit and Aspha-min, crumb rubber has also added to assess its impacts on WMA characteristics. The outcomes of this research indicated that Aspha-min reduced the indirect tensile strength of the mixtures, the two WMA additives raised the rut deepness of the mixtures, and both of the additives minimized the TSR of the mixtures [18].

2. Research objective
This study aimed to evaluate the effect of increasing the sasobit content on both moisture and rutting resistance of asphaltic mixtures, by determining the rutting impression using HWTD, whereas the strength and stiffness of the mixtures were determined using the IDT test for conditioned and unconditioned samples.

3. Materials
3.1. Asphalt cement
The asphaltic cement was chosen for this investigative process-with a penetration grade of (40/50)-was obtained from the Refinery of AL-Daurah base bitumen (AC40/50). Table 1 presents the physical characteristics of the asphalt cement as by (ASTM Standard Designation).

3.2. Aggregates and mix type
The aggregates used for this work have been selected from Quarry of al-Nibaue, which was widely used in the production of asphalt mixture. Laboratory experiments were used to quantify the chemical and physical characteristics according to (ASTM Standard Designation) for coarse and fine aggregate as exhibited in tables 2 and 3, respectively.
Table 1. Physical characteristics of asphalt binder and standards limitations.

| Tests                                      | Standard       | Tests value | Standards Limitations as per to SCRB / R9, 2003 |
|--------------------------------------------|----------------|-------------|-------------------------------------------------|
| Penetration, 25°C, (0.1 mm)                | ASTM. D 5      | 48          | 40-50                                           |
| Ductility, 25°C, 5cm./min.                 | ASTM. D 113    | +140        | >100                                            |
| Softening Point. (°C)                      | ASTM. D 36     | 51.5        | ----                                            |
| Specific gravity, 25°C                     | ASTM. D 70     | 1.045       | ----                                            |
| Flash & fire points                        | ASTM. D 92     | 295°C & 302°C| > 232 °C                                       |
| Rotational Viscosity a (centistokes)       | ASTM. D4402    | 543 @ 135°C |                                                  |
|                                            |                | 157 @ 165°C |                                                  |

a The test was done in Asphalt Laboratory of civil Engineering Department, University of Karbala.

Table 2. Laboratory results from physical properties of the coarse aggregates.

| Test in laboratory                        | ASTM Designation | Results | Specification |
|-------------------------------------------|-------------------|---------|---------------|
| Apparent Specific gravity                 | ASTM C127         | 2.661   | ----          |
| Bulk Specific gravity                     |                   | 2.625   | ----          |
| Absorption, %                             |                   | 0.362   | ----          |
| Angularity                                | ASTM D 5821       | 97%     | Min. 95%      |
| Soundness                                 | ASTM C88          | 4.1     | Max. 12%      |
| Flat                                      |                   | 1.1%    |               |
| Elongation                                | ASTM D4791        | 2.8%    | Max. 10%      |
| Toughness, by (Los Angeles Abrasion)      | ASTM C535         | 20.8%   | Max. 30%      |

Table 3. Laboratory results from physical characteristics of the fine Aggregate.

| Test in laboratory                         | ASTM             | Test result | Specifications |
|-------------------------------------------|------------------|-------------|----------------|
| Specific gravity (Apparent)               | ASTM C128        | 2.642       | ----           |
| Bulk Specific gravity                     |                   | 2.615       | ----           |
| Absorption, %                             |                   | 0.480       | ----           |
| Equivalent sand (clay content)            | ASTM D2419       | 86.5%       | Min. 45%       |

The nominal maximum size of the aggregate chosen for the aggregate gradation - used in asphaltic concrete mix - for the trail specimens for wearing course - was 12.5 mm according to the Iraqi State Corporation for Roads and Bridges (S.C.R.B.), as illustrated in table 4.

3.3. Warm mix additive

The modifier additive included in this work was Sasobit as shown in figure 1, which is extracted from the process of gasification of coal. It is manufactured by the company of Sasol Wax. The chemical composition of Sasobit consisted of fine crystalline in a long chain-hydrocarbons, production by different ways of synthesis of Fischer tropsch (F-T). The long-chain contained carbon atoms ranging from 40 to 115 carbon atoms. The point of melting of the Sasobit additive, as mentioned by the producer, was about 100 °C to 105 °C, and it was completely dissolved in bitumen at a temperature over 115 °C [8]. Table 5 shows the rheological Characteristics of Sasobit.
Table 4. Gradation of asphalt Mix.

| Sieve Size | % Passing as by(SCRB/ R9, 2003) wearing course type IIIA | Work choice |
|-------------|-------------------------------------------------------------|--------------|
| Standard Sieves | Min. | Max. | %passing | %Retaining |
| 19.00mm 3/4" | --- | 100 | 100 | 0 |
| 12.50mm 1/2" | 90 | 100 | 95 | 5 |
| 9.500mm 3/8" | 76 | 90 | 83 | 12 |
| 4.750mm #4 | 44 | 74 | 59 | 24 |
| 2.360 mm #8 | 28 | 58 | 43 | 16 |
| 0.300mm #50 | 5 | 21 | 13 | 30 |
| 0.075mm #200 | 4 | 10 | 7 | 6 |
| Pan | --- | | 7 | |

The type of asphalt mixture was densely graded and the optimum asphalt cement content was found based on Marshall mix design method ASTM D 6926-10 and ASTM D6927, 15.

Table 5. Rheological Characteristics of Sasobit [8].

| Parameters | Congealing Point, °C | Penetration at 25°C | Penetration at 65°C | Laboratory Melting, °C | Brookfield Viscosity At 135°C, mPa.s |
|------------|----------------------|---------------------|---------------------|-----------------------|-----------------------------------|
| Max        | 100                  | 0                   | 0                   | 75                    | 10                                |
| Min        | 110                  | 2                   | 13                  | 115                   | 15                                |

Figure 1. Sasobit organic additive material.

3.4. Modified Asphalt Binder
Four different percentages of Sasobit (1%, 2%, 3%, and 4%) were mixed with the asphalt binder (40/50 penetration) to production the modified asphaltic binder. In order for the Sasobit to be thoroughly mixed with the asphalt, binder must have been heated. After the binder had been heated to 150° C, the Sasobit was added and mixed together with a propeller mixer to obtain the WMA.

4. Mix design
The design of the HMA and WMA mixes was carried out by following the Marshall procedure according to the ASTM D 6926 - 10 and ASTM D6927 – 15. The specimens have been compacted with 75 Marshall Hammer blows applied at each side of the specimen. Both of the traditional hot and warm mixes were mixed and compacted at temperatures shown in table 6 depending on the relationship between the viscosity and the temperature by the rotational viscosity at temperatures of 135° C and 165° C utilizing the Brookfield viscometer test of binder according to (ASTM D4402-15, 2015).
Table 6. production and placement temperatures.

| Mix type       | Production temperatures (°C) | Placement temperatures (°C) |
|----------------|-----------------------------|----------------------------|
| HMA            | 161 – 167                   | 148 – 154                  |
| WMA – 1% Sasobit | 158 – 164                   | 145 – 151                  |
| WMA – 2% Sasobit | 152 – 158                   | 139 – 145                  |
| WMA – 3% Sasobit | 143 – 148                   | 131 – 136                  |
| WMA – 4% Sasobit | 140 – 146                   | 128 – 134                  |

5. Laboratory Work

5.1. Sample Preparation

For HMA mixtures, three specimens were prepared for each percentage (4, 4.5, 5, 5.5, and 6%) of 40/50 asphalt binder using Marshall mix design method according to (ASTM D6926 - 10) and (ASTM D6927 - 10), then determining the volumetric characteristics, Marshall stability and flow value to select the optimum asphalt content. Asphaltic mixtures were produced and placed at asphalt temperatures as shown in table 6 proper to viscosity of 170 ± 20 and 280 ± 30 centistokes, respectively (Asphalt Institute, 2015) [19]. In the same way, specimens were prepared for WMA mixtures and for each percentage of Sasobit which were (1, 2, 3 and 4%). All the specimens of all mixtures (HMA and WMA) were subjected to further tests (stability of Marshall and flow value, wheel track test to evaluate rut resistant and indirect tensile strength to assess moisture damage).

5.2. Tests

5.2.1. Marshall Test. In this test, firstly the bulk specific gravity of each specimen (ASTM D2726-08), theoretical specific gravity (maximum) (ASTM D 2041- 03), and percentage of air void (STM D3203-05) were calculated. Secondly, the Marshall stability and flow measurements were performed for each sample as by (ASTM D 1559, 2015) in order to find the optimum asphaltic content. The optimum asphalt binder was (5.0 percent) which was obtained from the average asphalt binder content of highest stability, highest unit weight, and 4% air voids from the results exhibited in table 7. Finally, the obtained optimal content of the asphalt binder was used to prepare new Marshall specimens which were subjected to the tests. Figure 2 exhibits the Marshalls stability and flow test.

Table 7. Volumetric Properties of HMA with Different Asphalitic Contents.

| Binder Content | stability (KN) | Flow (mm) | Unit Weight (gm/cm3) | Air Voids % | V.F.A % |
|----------------|----------------|-----------|----------------------|-------------|---------|
| 4.0            | 9.24           | 1.8       | 2.268                | 7.372       | 50.102  |
| 4.5            | 9.93           | 2.5       | 2.289                | 6.062       | 58.341  |
| 5.0            | 10.92          | 2.8       | 2.317                | 4.201       | 70.230  |
| 5.5            | 10.33          | 3.2       | 2.310                | 3.228       | 77.354  |
| 6.0            | 8.40           | 3.9       | 2.299                | 2.554       | 87.699  |
5.2.2. Moisture Susceptibility. An indirect tensile strength test according to (ASTM D6931-12, 2007) was carried out on both types of HMA and WMA samples to find the moisture sensitivity of these mixtures. For this test, the samples were prepared and compacted utilizing the Marshall mix design procedure, Marshall hammer to an air voids level of 7% ± 1%. Subset of three samples were prepared at normal condition (dry) and another subset of three specimens were prepared after moisture conditioning (wet). The moisture conditioning (wet) samples were exposed to a vacuum to obtain of 55–80% saturation of the samples. Subsequently, the specimens were soaked in water path at 60°C ± 1°C for 24 h, and then placed in a water bath at 25 °C ± 1°C for 1 hour. The dry samples were putted in a water bath at 25 °C for 20 min. All specimens (dry and wet) were then tested in indirect tensile testing (IDT) at 25°C, and prior to determining the forces required to break the specimens. The tensile strength ratio (TSR) was calculate based on the ratio of condition to uncondition IDT. The minimum requirement of TSR value was 80% according to (ASTM D4867M-09, 2014).

Although, the tensile strength of asphalt pavement is not as significantly strong as its compression, the tensile strength is still important in various pavement applications. Pavement engineers are interested in tensile characteristics of the asphaltic mixture because of the related cracking problems. The tensile properties are determined by the indirect tensile strength test (IDT) which are also related to the cracking characteristics of the pavements as studied by a group of researchers [20]. The higher tensile strength is, the stronger cracking resistance gets. Indirect tensile strength (IDT) test was conducted to all samples by applying constant loading rate of 5 cm/min at 25 °C along the middle point of 12.70 ± 0.3mm span until the samples failed from vertical deformation. The maximum load recorded for determining tensile strength is as in equation (1).

\[
\text{St} = \frac{2000P}{\pi Dt}
\]  

(1)

Where, \(\text{St}\): Tensile strength (kPa), \(P\): Maximum load (N), \(T\): height of sample (mm), and \(D\): diameter of sample (mm).

The TSR (tensile strength ratio) is a ratio between the indirect tensile strength of the wet (condition) specimen and that of the dry (uncondition) specimen. The TSR value was calculated for all mixes as in equation (2). Typically, TSR value should be greater than or equal to 80% which is acceptable resistance to moisture damage. Figure 3 shows some of the samples prepared and tested.

\[
\text{TSR} = \frac{\text{St}\text{m}}{\text{Std}} \times 100\%
\]  

(2)

Where, \(\text{TSR}\): Tensile strength ratio (%), \(\text{Stm}\) : average tensile strength of the moisture-conditioned (wet) Subset (kPa), and \(\text{Std}\): average tensile strength of the dry subset (kPa).
5.2.3. Rutting Resistance. The roller compactor could provide a pneumatically powered means of compacting slab of asphalt material in the laboratory under conditions, which was simulated in-situ compaction. At this study, compaction of asphalt concrete slabs for the test of rutting was conducted at 4.0 percent air voids using Roller Compactor Device at National Center for Construction Engineering Laboratories (NCCL) according to the AASHTO: (T 312 - 2010) and (BS EN 12697 - Part 33 : 2003). A compacted slab with dimensions of (40 cm x 30 m x 5 ± 0.6 cm) was prepared according to (BS EN 12697 - Part 22 : 2003). The asphaltic concrete mix for both (HMA and WMA) was then placed in an oven at 135ºC for 4 hours, being exposed to short-term aging for compaction.

Subsequently, compaction was done by the Roller of Compaction (BS EN 12697 - part 33 : 2003). At the required compaction temperature, the mold and the plate were putted in the oven, being heated to ensure that the mixing temperature was not minimized. The load from 7.0 kN to 10.0 kN was applied to get adequate compaction with ample air voids. Figure 4 illustrates the roller compactor apparatus, mold, and Slab Specimens. The pavement wheel tracker is a system that simulates road conditions to monitor the rutting of asphalt mixes. Under BS EN 12697-22:2003, AASHTO: T324 – 2013, the test was carried out. The test gave information on the permanent deformation rate resulting from the moving concentrated loads. Having about 700 N of a load, a loaded wheel was placed at a contact point being moved repetitively on top of the specimens for up to 20,000 cycles back and forth. Figure 5 illustrates the testing of specimens slabs of asphalt concrete mixes.

![Figure 3. Indirect Tensile Strength Test](image)

Figure 3. Indirect Tensile Strength Test (A) vacuum of specimen, (B) water bath at 60°C, (C) water bath at 60°C, (D) unconditioned specimens test, (E,F) conditioned specimens test.

![Figure 4. Preparing Slab Specimens by Roller Compactor](image)

Figure 4. Preparing Slab Specimens by Roller Compactor.

![Figure 5. Wheel Track Test and tested specimens](image)

Figure 5. Wheel Track Test and tested specimens.
5.3. TEST RESULTS AND DISCUSSION

5.3.1. Marshall stability volumetric properties. The volumetric properties at optimum asphaltic content (5.0 %) by weight of overall mix and Iraqi State Corporation for Roads and Bridges (S.C.R.B, 2003) specifications for asphalt mixes used as a surface course are exhibited in table 8.

| Mix type          | Air voids or voids in total mix (%) | voids in the mineral aggregate (%) | voids filled with asphalt (%) |
|-------------------|-------------------------------------|-----------------------------------|-----------------------------|
| HMA               | 3.90                                | 16.15                             | 75.30                       |
| WMA – 1% Sasobit  | 4.35                                | 16.21                             | 74.80                       |
| WMA – 2% Sasobit  | 4.20                                | 16.10                             | 75.15                       |
| WMA – 3% Sasobit  | 4.00                                | 16.00                             | 75.35                       |
| WMA – 4% Sasobit  | 3.80                                | 15.84                             | 75.60                       |
| SCRB specifications | (3 – 5) %                         | -------                           | (70 – 85) %                  |

The effect of the addition of Sasobit to asphalt binder on Marshall stability and flow value is shown in figures 6 and 7. For the comparison between WMA mix and conventional HMA mix, as shown in these Figures, the Marshall stability of the hot mix was (10.5 kPa). The Marshall stability of the WMA mixes raised with the augmentation of the dosage of Sasobit content from (10.85 kPa) for (1.0%) Sasobit to (12.97 kPa) for (4.0%) Sasobit. The mix with (1.0%) of Sasobit represented the lowest value of Marshall Stability which was greater than the hot mix by (3.2%). For the percent (4.0%), the Marshall Stability was at the highest value which was greater than the control hot mix by (19.0%). Moreover, the Marshall Flow was greater than the control mix by (6.7%) for this percentage (4.0%) and 3.0% of sasobit content. The highest value of Marshall Flow for the WMA mixes was observed in (1.0%) Sasobit, while the lowest value appeared in the (3.0%) and (4.0%) Sasobit. That could be due to the high stiffness and low air voids of the mixes, and this usually tends to improve the flow values.

Overall, all warm mixes were greater than the hot mixture. Also, all mixtures for warm asphalt and hot asphalt exceeded the minimum limit of Marshall Stability, which was (8.0 kN), and did not exceed the range limit of Flow number which was (2.0 – 4.0) mm recommended by (SCRB \ R9, 2003) for wearing course.

Figure 6. Effect of Sasobit content on Marshall Stability.
5.3.2. Moisture Susceptibility. Figure 8 below, shows the indirect tensile strength for unconditioned (dry) sample and conditioned (wet) sample. The IDT (indirect tensile strength) for unconditioned (dry) specimen increased steadily with the growth of Sasobit percentage until (2.0 %), followed by a steady fall at (3.0%) which was the minimum value. This was also followed by a steady rise at (4.0%) of Sasobit which was the maximum value. As it can be noticed in this figure, the growth in Sasobit percentage led to a growth in IDT for unconditioned (dry) specimen. IDT raised by (5.6%) when Sasobit percentage raised to 4.0 per cent. The indirect tensile strength for conditioned sample drop at (1.0%) Sasobit was compared with the control HMA. This was followed by a slight increase at (2.0%) Sasobit, and then fell slightly at (3.0%) followed by a steady rise at (4.0%) Sasobit. The minimum value was at (1.0%), and the maximum value was at (4.0%). All the values of Sasobit content were less than the control mix for the conditioned samples.

The TSR (tensile strength ratio) was used to estimate the sensitivity of the mixtures to moisture. The minimum acceptable limit of (80 percent) for the (TSR) ratio was used to differentiate between susceptible and resistant mixtures to the moisture.

Figure 9 shows the TSR ratio for varying content of Sasobit. The higher value was (90%) for conventional HMA, but then the ratio suddenly fell to (82%) for (1%) Sasobit percentage of WMA. This was followed by a steady increase until reaching (87%) for (4%) Sasobit content. All the warm
mixes asphalt were less than the hot mix. They exceeded the minimum limit of Tensile Strength Ratio (TSR) which was (80%) as recommended by (ASTM D4867M-09, 2014). This is due to the reality that the Sasobit causes a hardened binder that has grown lower in viscosity as the time goes by. This will increase the efficiency of mixtures with high viscous materials under tension, resulting in a decrease in strength when subjected to adverse conditions of high moisture and temperature.

As noted in Figure 4, the values of TSR of all WMA were under the traditional HMA. This means that adding Sasobit increased the potential for moisture damage, as previous studies (local and international) found and included [17], [18], [21], [22], [23], [24]. The increasing potential for moisture sensitivity of Sasobit WMA could be due to the reduced temperatures of the production and placement of mixes, which could lead to incomplete aggregate drying. Hence, water confined in coated aggregate causes a higher sensitivity to moisture. This study showed the WMA was more susceptible than the traditional HMA, and this was in agreement with different studies[25, 26].

![Figure 9. Effect of Sasobit content on Tensile Strength Ratio.](image_url)

### 5.3.3. Rutting Test Results.

For both types of mixtures (HMA and WMA), the rut depth data in mm was obtained using the wheel tracker testing as exhibited in figure 10, which represents the relationship between rut depth and Sasobit content. For the comparison between WMA containing Sasobit with the traditional HMA mixture, as shown in this Figure, the WMA rutting resistance is higher than HMA. The addition of Sasobit to mix led to minimize the rut deepness with respect to traditional HMA. Rut depth gradually fell with the raise of Sasobit content. Compared with the reference HMA, rut depth of WMA was less than the rut depth of HMA by (16.0%), (42.60%), (62.90%), and (71.10%) with Sasobit percentages of (1.0%), (2.0%), (3.0%), and (4.0%) respectively at 60ºC testing temperature, being corresponding to some local studies [17], [18], [27].

The rut data obtained being based on the results of wheel tracker testing indicated that rut depth of warm asphalt mix appeared to be lower than that of the traditional hot asphalt mix. Adding up to 2.0 percent of Sasobit to WMA appeared to be more sensitive to deformation compared to other warm mixtures, while the best values for deformation resistance were 3 percent and 4 percent of Sasobit.

This mentions that the Sasobit adding to the WMA mixture raised the resistance of rutting for the mixes. Compared with HMA mixtures, the WMA mixtures became stiffer and thus had greater resistance to rutting. This finding is due to the crystallized structure resulted from the organic WMA additive modifying the impact [28], and based on the fact that asphalt cement improved when sasobit had a high viscosity at low and medium temperatures (less than 90 degrees Celsius), while the viscosity decreased at high temperatures (more than 100 ºC) as stated by a number of researches [5], [29, 30].
Figure 10. Effect of Sasobit content on Rut depth.

From the results of the tests conducted on asphalt cement and asphalt mixtures by adding the Sasobit as a warm additive in percentages of 1, 2, 3 and 4% to produce warm asphalt mixtures, it was found that the percentage of the additive 4% Sasobit was the best one.

6. Conclusions and recommendations
6.1. Conclusions
1. With the addition of sasobit, rutting resistance steadily increases and the best result is obtained with the addition of 4% sasobit, which gives a 71.1% increase in rutting resistance compared to HMA, and this agrees with the researcher [16].
2. The addition of Sasobit increases the moisture damage as the strength of wet samples is lower than that of dry samples, which in turn reduces the TSR, but it is still much higher than the minimum of 80%. TSR for all mixtures is greater than 82% while it is 87% at 4% Sasobit.
3. Sasobit modified asphalt binder can improve the coatability at lower mixing temperature for WMA, as we have observed that all mixtures were workable, easy to compact with lower emissions during the production.
4. Overall, WMA mixtures prepared with Sasobit used in this study perform better than HMA mixtures in terms of rutting characteristics. Beside the modification effects of WMA additives, the lower amount of aging due to lower production temperatures of the warm additive plays an important role in the total assessment of these innovative technologies.

6.2. Recommendations
1. The use of 2% sasobit will provide better results in terms of permanent deformation and moisture damage, with additional reduction in production temperatures and thus saving fuel cost to the contractor as well as reducing environment pollution.
2. Economically, the percentage 3% Sasobit can be used because its results are very close to 4% in terms of stability, TAR, and rut depth.
3. When the WMA techniques are used for the purpose of producing mixtures with lower temperatures, it is substantial to use these temperature of WMA in the plant and in the field to ensure that the benefits of the warm mixes are achieved for this purpose.

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