Laboratory Evaluation of rutting performance of warm mix asphalt with Nano base and Fischer-Tropsch wax additive

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ABSTRACT

Mixing temperature of asphalt concrete can be lower using new technology called warm mix asphalt (WMA). WMA technology has lots of advantages such as needing less energy, emitting less gaseous pollutants and having less construction cost. However, this technology has some unfavorable features such as high moisture susceptibility. Different kinds of WMA additive improve resistance of mixtures against moisture damage substantially. On the other hand, some other features of WMA mixtures produced using WMA additive like resistance to permanent deformation need more investigations. In this study the Marshall and rutting performance of Nano base mixtures were investigated and compared to Fischer tropsch wax mixtures as control mix. The results indicated that the mixtures containing Nano base additive had less marshal stability and rutting resistance than Fischer tropsch wax mixtures.

Keywords: Additives, Warm Asphalt Mixture

Laboratory Evaluation of rutting performance of warm mix asphalt with Nano base and Fischer-Tropsch Wax additive

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ABSTRACT

Mixing temperature of asphalt concrete can be lower using new technology called warm mix asphalt (WMA). WMA technology has lots of advantages such as needing less energy, emitting less gaseous pollutants and having less construction cost. However, this technology has some unfavorable features such as high moisture susceptibility. Different kinds of WMA additives improve resistance of mixtures against moisture damage substantially. On the other hand, some other features of WMA mixtures produced using WMA additive like resistance to permanent deformation need more investigations. In this study, the Marshall and rutting performance of Nano-Based (NB) mixtures were investigated and compared to Fischer-Tropsch Wax (FTW) mixtures as control mix. The results indicated that the mixtures containing NB additive had less Marshall stability and rutting resistance than FTW mixtures.

KEYWORDS:, *Rutting, Warm mix asphalt, Wheel track.*

1. INTRODUCTION

The warm mix technology, which is used widely in recent decades, allows the asphalt concrete to be mixed at 10-30$^{\circ c}$ lower than conventional Hot-Mix asphalt. This reduction in temperature not only saves energy, but also reduces fumes and greenhouse gases emitted during the construction of asphalt pavements and makes it more environmentally friendly [1].

On the other hand, asphalt pavements are meant to withstand progressively large loads at different environmental conditions. Premature deterioration in such pavements may cause serious concerns in terms of safety and economic issues. To prevent this phenomenon and to improve the functional properties of asphalt mixtures, many polymer and nano-based additives are introduced to modify the bitumen or mixtures. The modification of binder with nanomaterial is somehow a new technology, which needs more investigation. In the last decade or so, nanotechnology has shown a considerable potential to greatly enhance the performance of bituminous materials. Nanomaterials are defined as materials having constituents of nanoscale dimensions that at least one of their external dimensions is in the size range of 1–100 nm. These materials have been in interest of pavement researchers because of their high surface area and different properties from normal materials [2].

Moisture susceptibility is one of the major distresses of asphalt mixtures and is more likely to happen when WMA technology is used [3]. The NB additive makes it possible to produce asphalt mixtures at lower temperatures by decreasing the viscosity of bitumen [4]. Although the positive impact of NB-WMA additive on moisture resistance of asphalt mixtures has been reported by the manufacturer and other researchers [5], other properties such as rutting behavior of asphalt mixtures containing this additive needs to be investigated. Therefore, in this study, the rutting performance of warm mix asphalt mixtures was investigated. For this purpose, dynamic creep and wheel track tests were conducted on laboratory manufactured specimens. As FTW is a common WMA additive and is widely used in technology, WMA mixtures produced with FTW additive was used as control mixture.

2. Material and Methods

The main procedure of this study was divided in 2 major phases. At first the optimum binder content of asphalt mixtures was determined using Marshall procedure in accordance with ASTM D1559 or AASHTO T 245, and at second phase, dynamic creep and the wheel tracker tests were conducted on the produced specimens to evaluate the impact of NB additive on rutting behavior of asphalt mixtures.

2.1 Basic Materials

2.1.1 Binder and aggregates

Crushed limestone aggregates provided from Tello quarry, placed at north east of Tehran were used for this study. The physical properties of aggregates are presented in table 1. AC 60/70 base bitumen was also provided from Pasargad Oil Company. The properties of the bitumen are presented in tables 2. In this study, aggregate grading curves were obtained from Iran Highway asphaltic pavements Code.No.234. The midline gradation of the aggregates used in the mix design is shown in figure 1.

2.1.2 Binder additive

In this research, two different WMA binder additives were employed. FTW is widely used as WMA additive in order to reduce the viscosity of binder and produce mixtures at less temeratures. The technical properties of this additive are shown in table 3. FTW is a long chain aliphatic hydrocarbon (chain lengths of 40–115 carbon atoms) obtained from coal gasification using the Fischer–Tropsch process [6]. Based upon the available literature, this additive is usually used at dosages of 1.5% to 3% [7, 8]. In this study, 3% FTB were added to bitumen at the temperature of 120◦C. Nano-Based WMA additive is a water-soluble organosilane that improves workability and decreases manufacturing and application temperatures. Based on the manufacturer recommendations, it can be either sprayed on aggregates (5% by weight of aggregates) before processing or it can be added to binder at 0.1%-0.15% by weight of asphalt binder. Therefore, 0.1% of NB additive was added to bitumen by weight of total bitumen and was mixed with low-shear mixer for 3 minutes. The mixing temperature was 120◦C. The properties of the NB additive are shown in table 4.

Table 1: Physical properties of mineral aggregates used in this study

Physical properties	Standard test	Value
Specific gravity (fine agg.)	ASTM C127	2.65
Specific gravity (coarse agg.)	ASTM C128	2.64
Water absorption	ASTM C127	0.9
Los Angeles abrasion (%)	ASTM C131	21.4

Table 2: Properties of base asphalt binders

test	Standard test	AC60/70
Viscosity Test at 135°C (cSt)	ASTM D2170	354
Penetration Test (0.1 mm)	ASTM D5	61
Ductility Test (cm)	ASTM D113	100
Softening point (°C)	ASTM D36	48
Flash point (°C)	ASTM D92	310
Specific Gravity	ASTM D70	1.02

Table 3: Technical properties of Sasobit

Characteristics	Description

melting Point (◦C)	105
Density (kg/m3)	620
Penetration @ 65 ◦C (d mm)	<1
Penetration @ 25 ℃ (d mm)	6
Appearance	Prills with 1mm diameter

Table 4: Technical properties of Zycotherm

Characteristics	Description
Flash Point (◦C)	>80
Density (kg/m^3)	1010
Freezing Point (◦C)	5
Solubility	Miscible with water
Viscosity at 25 ◦C(CPS)	400-1000
Appearance	Liquid- Pale yellow

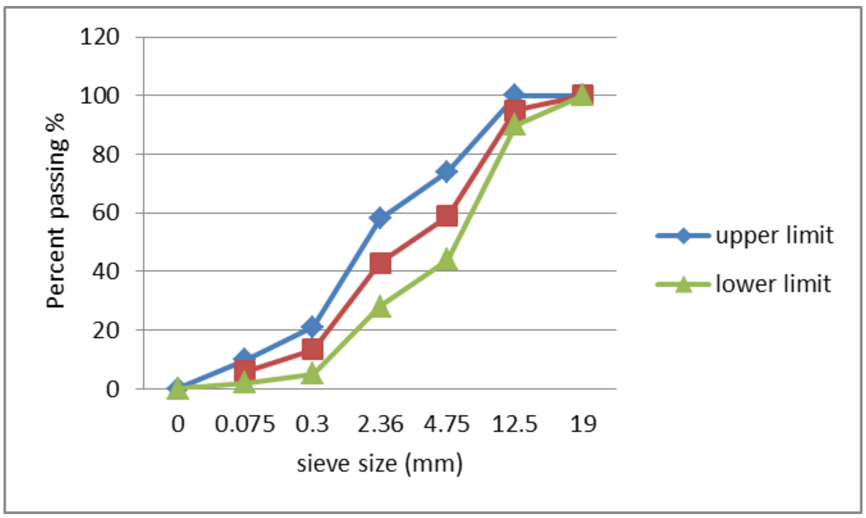

Fig 1: Gradation of designed aggregates

2.1.1 Sample preparation

18 specimens for each type of mixtures were prepared for Marshall tests. To do so, aggregates were heated to 135◦C for 24 hours and heated bitumen containing WMA additive was added and mixed for up to 5 minutes. For compacting Marshall specimens, Marshall hammer were used for 75 cycles for each side of specimens in accordance with ASTM D1559 or AASHTO T 245. After the optimum binder content, specific gravity and maximum bulk gravity had been found for each mixture, SuperPave gyratory compactor and roller beam compactor was used to prepare specimens for dynamic creep and wheel track tests respectively.

2.2 Testing program

2.2.1 Marshall Tests

The Marshall stability test is used in highway engineering for both mix design and evaluation. Although Marshall method is essentially empirical, it is useful in comparing mixtures under specific conditions [9-11]. Marshall stability and flow test was carried out on specimens with various bitumen contents and the optimum bitumen content was obtained according to ASTM D1559 or AASHTO T 245. Three specimens from each mixture were placed in a 60◦C water bath for 30-40 minutes, after submerging the specimens for the required amount of time, the specimens were immediately subjected under a loading rate of 51 mm per minute until occurrence of failure. The Bulk specific gravities and air void contents of specimens were measured in accordance with AASHTO T 166 and AASHTO T 209 respectively.

2.2.2 Dynamic creep test

Rutting which is defined as the Surface depression in the wheelpath in asphalt layers is one of the major distresses in asphalt pavements [12-15]. In order to measure the resistance of asphalt mixtures to permanent deformation, dynamic creep test is thought to be one of the best methods [16]. In this research, dynamic Creep test was conducted based on Australian AS289-12-1, and the specimens were placed under a repeated uniaxial stress and the deformation in the same direction of loading was measured using linear variable differential transducers (LVDT). Typically rutting is more likely to happen in high temperatures and under heavy loads [17]. Thus, to simulate the worst environmental conditions the test was conducted at 50 ◦C and the devices chamber was used to maintain the constant temperature. At first, 3 specimens from each type of mixture were placed in an environmental chamber at 50◦C for 5 hours. Then a pressure of 450 KPa was applied to specimen with 0.5 s loading and 1.5 s rest time for each loading cycle and the axial deformation was measured. The Universal Testing Machine (UTM-5P) was used for this purpose. A typical creep test curve is shown in Fig. 2. This curve is divided into three major phases. In the primary phase, the strain rate decreases which is due to high initial air void and volumetric changes. In the secondary phase, the strain changing rate is constant, and in the tertiary phase the plastic deformation rate dramatically increases which occurs at high stress levels [18]. Flow number, which is defined as the number of cycle in which the territory phase is started and permanent strain in the specimen dramatically increases was chosen as criterion to compare the mixtures resistance to permanent deformation. The flow number can be correlated with rutting potential [19].

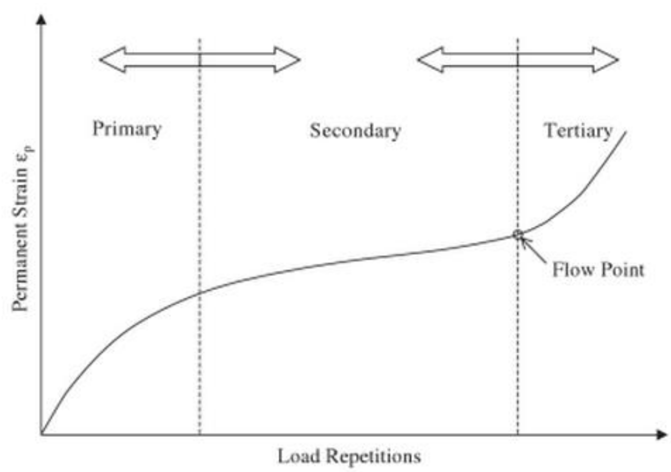

Fig.2: Typical creep test curve [18]

2.2.3 Wheel tracking test

The wheel track devices are used to measure the rut depth of asphalt mixtures. Three most prominent namely Asphalt Pavement Analyzer (APA), Hamburg Wheel Tracking Device and French Rutting Tester are used for this purpose. These devices measure the potential of rutting by rolling a loaded wheel device repeatedly across an asphalt mix specimen. The cumulative rut depth is then measured and used as rutting criterion. In this research, the Iran University of Science and Technology ABRC Wheel Track machine was used to measure the rut depth of asphalt mixtures at 50◦C in accordance with AASHTO T324. The specimens were subjected in the test conditions 5 hours prior to running the test. The load on the wheel was 705 ± 4.5 N. The specimens were prepared using the rolling machine at designed bitumen content and 4% air void.

3. Results and discussion

3.1 Marshall test results

The Marshall Test results of each type of mixture which are the average of 3 specimens are presented in table 5 and Figures 3 and 4. Based on the results, the optimum bitumen content obtained from maximum Marshall stability, maximum specific density and 4% air void, does not change significantly by changing the WMA additive. The Marshall stability, of the mixtures made with FTW additive is higher than the the mixetures made using NB additive. The increase in Marshall Stability, which occurs by adding FTW additive, is because of the stiffened modified bitumen due to adding FTW additive. Other properties of asphalt mixtures namely bulk specific gravity, Flow and air void content are almost equal for both mixtures.

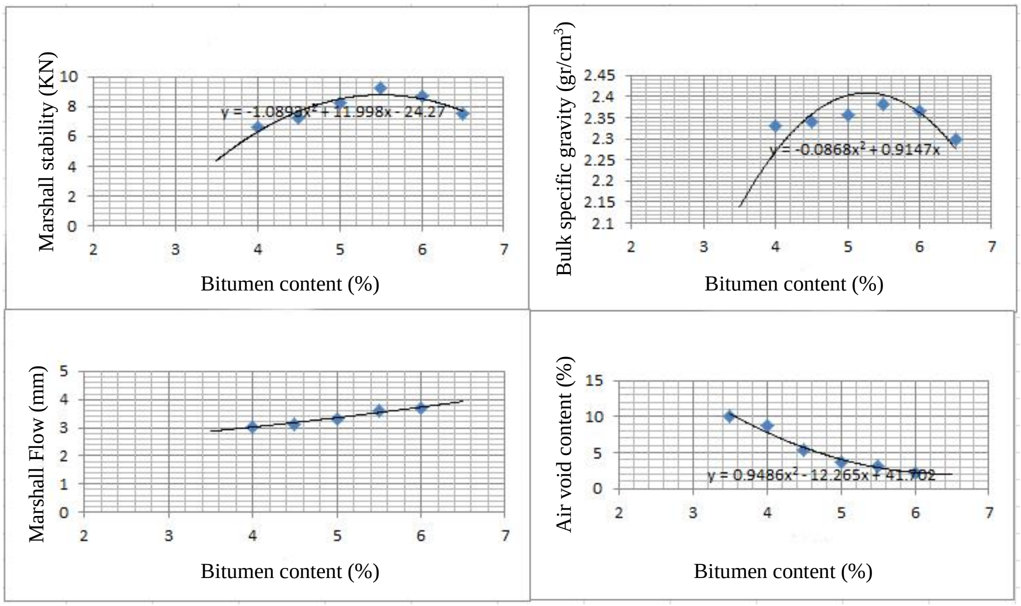

Fig 3: Marshall test diagrams for FTW WMA mixtures

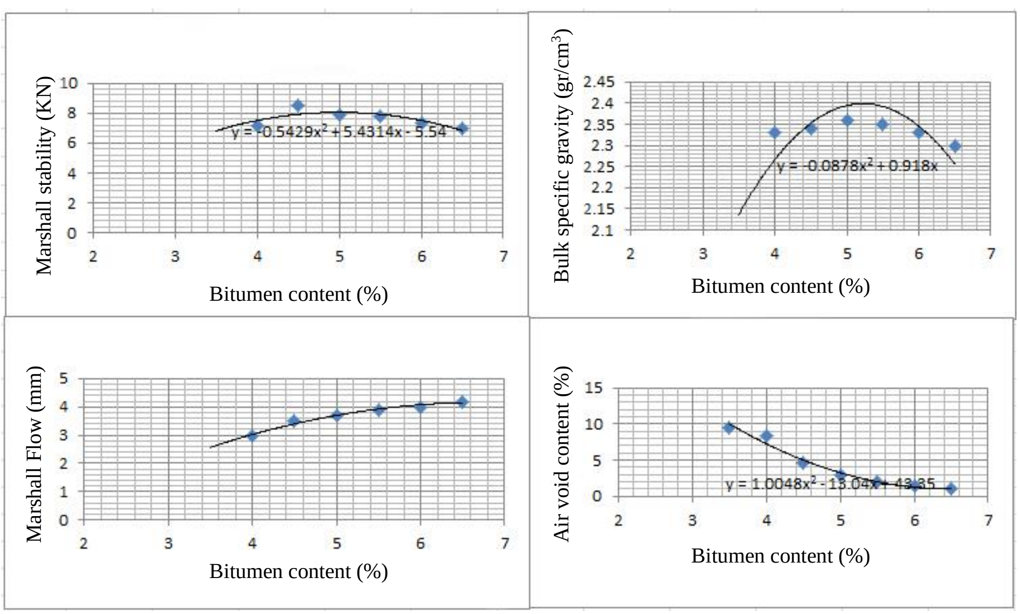

Fig 4: Marshall test diagrams for NB WMA mixtures

Table 5: Marshall test Results

Parameter	FTW	NB
Optimum bitumen content (%)	5.2	5
Marshall Stability (KN)	8.8	8.1
Marshall Flow (mm)	3.5	3.8
Bulk specific gravity (gr/cm^3)	2.38	2.39
Air void content (%)	3.8	4

3.5 Dynamic creep test

The dynamic creep test results are indicated in Figs 5 and 6. It can be seen that the resistance of mixtures produced with FTW additive is much higher than the mixtures produced using NB-WMA additive and the accumulated strain of NB-WMA mixtures under dynamic creep test is significantly higher than FTW-WMA mixtures. Furthermore, the flow number of FTW-WMA mixtures is almost 4 times higher than NB-WMA mixtures. On the other hand although the NB-WMA additive improves the moisture damage resistance of asphalt mixtures [5], they do not have any positive impact on the rutting performance of mixtures and are not appropriate to use in areas with hot environmental conditions.
Previous studies on rheological characteristics of bitumens containing FTW additive show that FTW additives change the rheological characteristics of bitumens, and the FTW modified bitumens have higher G^* value than base bitumens [7, 8]. However, little literature is available about the rheological characteristics of bitumens modified with NB WMA additive. As the mixtures produced with stiffer binders rut less, modifying bitumen with FTW-WMA additive leads to stiffer bitumen and can contribute to more rutting resistance [20]. In this research study, the flow number of FTW-WMA mixtures is almost four times higher than that of NB-WMA mixtures. This performance is due to stiffer FTW modified bitumen in FTW-WMA mixtures.

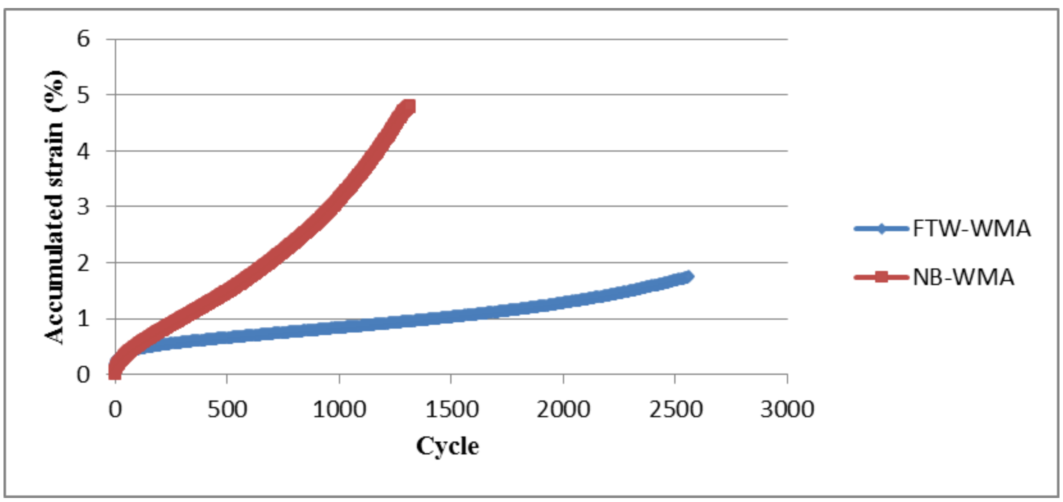

Fig 5: Dynamic creep test results

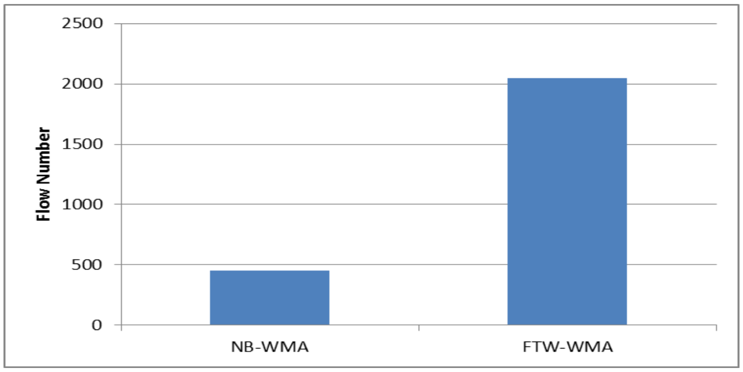

Fig 6: Flow number of the WMA mixtures

3.6. Wheel track test

The wheel tracking test results are presented in figure 7. It is seen that the results of wheel track tests are compatible with the results of dynamic creep test and the accumulated rut depth of WMA mixtures produced with NB additive is much higher than WMA mixtures made with FTW additive. However the discrepancy of two values is less in comparison with dynamic creep test.

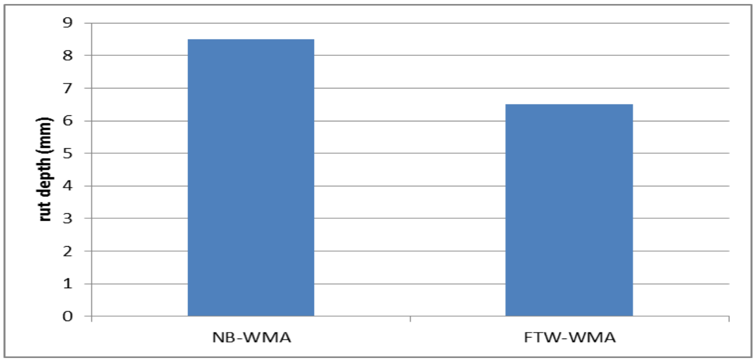

Fig 7: Wheel track test results

4. Conclusion

In this study, the performance of WMA mixtures containing produced using two different WMA additives (Fischer Tropsch Wax and Nano-based additive) was evaluated in terms of resistance to permanent deformation using dynamic creep and wheel track tests. The results are as follows:

- The optimum binder content and mix design of WMA mixtures do not significantly change by changing the WMA additive.
- The Marshall stability of the WMA mixtures produced with FTW technology is higher than the WMA mixtures containing NB additive.
- The bulk specific gravity, Marshall flow and air void do not change significantly by changing the WMA additive.
- The rutting potential of the mixtures produced with NB additive is much higher than mixtures produced with FTW additive, and the flow number of FTW-WMA mixtures is almost 4 times higher than NB-WMA mixtures.
- The wheel track test results agreed with dynamic creep test results and the rut depth of NB-WMA mixtures was higher than FTW-WMA mixtures.

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