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The Effects of Nano Bentonite and Fatty Arbocel on Improving the Behavior of Warm Mixture Asphalt against Moisture Damage and Rutting

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Abstract

The use of warm mix asphalt (WMA) technology has increased dramatically in recent years to protect the environment and reduce energy consumption. Despite numerous advantages, WMAs are less commonly used as a result of their lower performance in comparison to HMAs. One of the main reasons for the low performance of WMAs is their high moisture sensitivity. In recent decades, bitumen modifiers have been used to improve the performance of asphalt mixtures. One of the additives that has recently been used to modify the characteristics of bitumen, is bentonite. The grade of asphalt cement used in this study is PG 64 -22 and the Bitumen is modified with 1, 3, 5 and 7% nano bentonite. Also, 0.3% fatty Arbocel has been used for the preparation of WMA. Indirect tensile strength (ITS) test and Nicholson stripping test are used to determine moisture sensitivity and dynamic creep test and LCPC are also used to evaluate the rutting potential. The results indicate that, increasing the percentage of nano bentonite and applying 0.3% of fatty Arbocel improves the resistance of mixture against moisture damage. Also it was found that increasing the mixture hardness decreases the permanent displacement and rutting potential of WMAs. So, it is suggested that the consumption of these additives increases WMA's lifetime and decreases its maintenance cost.

Keywords: Warm Mix Asphalt; Dynamic Creep Modules; Rutting; ITS.

1. Introduction

Possible failures in WMAs are divided into four major groups: 1. Permanent deformation or rutting, 2. Fatigue or load associated cracking, 3. Low temperature or thermal cracking, 4. Moisture damages. WMA is an emerging technology, In line with concerns about global warming and energy consumption in asphalt industry. In WMA production, the mixing and compaction temperature are reduced from 10 to $38^{\circ}C$ compared to the HMA (Hot mix asphalt) that is produced and compacted at temperatures of 145 to $150^{\circ}C$ [1]. Production of temperature reduction results in reduced fuel consumption and manufacturing costs. It also reduces the amount of greenhouse gas emissions in asphalt production process [2]. Modified bitumen is one solution for improving the pavement performance [3]. Clay modified bitumen had been used since 100 years ago. As soon as the clay particle-page reaches inside the bitumen, it creates similar rebar properties inside reinforced concrete which improve bitumen performance against cracking and deformation in high temperatures [4]. Research shows that adding clay to bitumen increases bitumen softening point and decreases its elasticity which increases the resistance of hot mix asphalt against thermal cracking [5]. Adding nano

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clay and nano lime to the hot asphalt mixture increases the durability of the mixture against freeze -thaw cycles [6]. The use of nano-clay also increases surface free energy and fatigue resistance of HMAs [7]. Adding cement and nano clay together have been found to improve the initial strength and cracking resistance, and reduce moisture susceptibility of cold mix asphalts [8]. Bentonite is a type of clay with high plastic and colloidal properties; it mainly consists of montmorillonite minerals [9]. Studies on HMA containing nanoclay modified bitumen show that nanoclay improves the performance of HMA against moisture damages and rutting [10]. Bentonite improves the rheologic characteristics of asphalt cement and it against aging [11].

Researches on HMAs containing bentonite modified bitumen indicate that these types of mixtures have higher shear strength and longer fatigue life than conventional HMAs [12]. Bentonite improves the rheological properties of bitumen at low temperatures and increases the resistance of hot asphalt mixtures against thermal cracks [13]. Semi-hot additives such as sasubit and asphamine have no significant effect on the amount indirect tensile strength and moisture sensibility of WMAs [14]. Nano-Zycotherm improves the moisture sensitivity of WMAs, but its effect on failure of rutting has'nt been reported. Sasubit, are found to increase the hardness and modulus of WMAs and decreases their permanent displacements [15]. Recent studies have proved that the addition of Evotherm and paraffin wax was not effective against moisture susceptibility [16]. Also, based on research findings, the use of rubber enhanced resistance against permanent deformation of WMAs but could not affect fatigue resistance [17]. Warm mix asphalts containing styrene–butadiene–styrene (SBS) copolymer were found to have a good behavior against rutting damage [18]. A considerable number of researches have been done on nanoclay modified polymers. Variables that have a great impact on the final nanocomposite include the choice and the type of used clay, the components of the polymer used, and how to mix them [19]. Natural and synthetic fibers can improve the resistance of fracture and the performance of WMAs [20]. Studies show that cellulose fibers improve the moisture sensitivity of hot asphalt mixtures and help the adhesion between aggregates and bitumen [21]. Fibers containing Arbesol improves SMA resistance against failure and deformation and increases the efficiency of pavements [22].The additives containing Arbesol ZZ 8/1 take less energy for compaction of SMAs compared to nonadditive mixtures and improves its resistance against rutting, fatigue, and moisture sensitivity [23]. Synthetic macrofibres can help WMA's rutting resistance and improve their performance and life spans [24]. Based on the above-mentioned studies, the current study is aimed at performing a laboratory investigation on WMA mixtures containing nanobentonite and fibers through a mechanistic–empirical approach to determine the effect of different additives on increasing the service life of pavements.

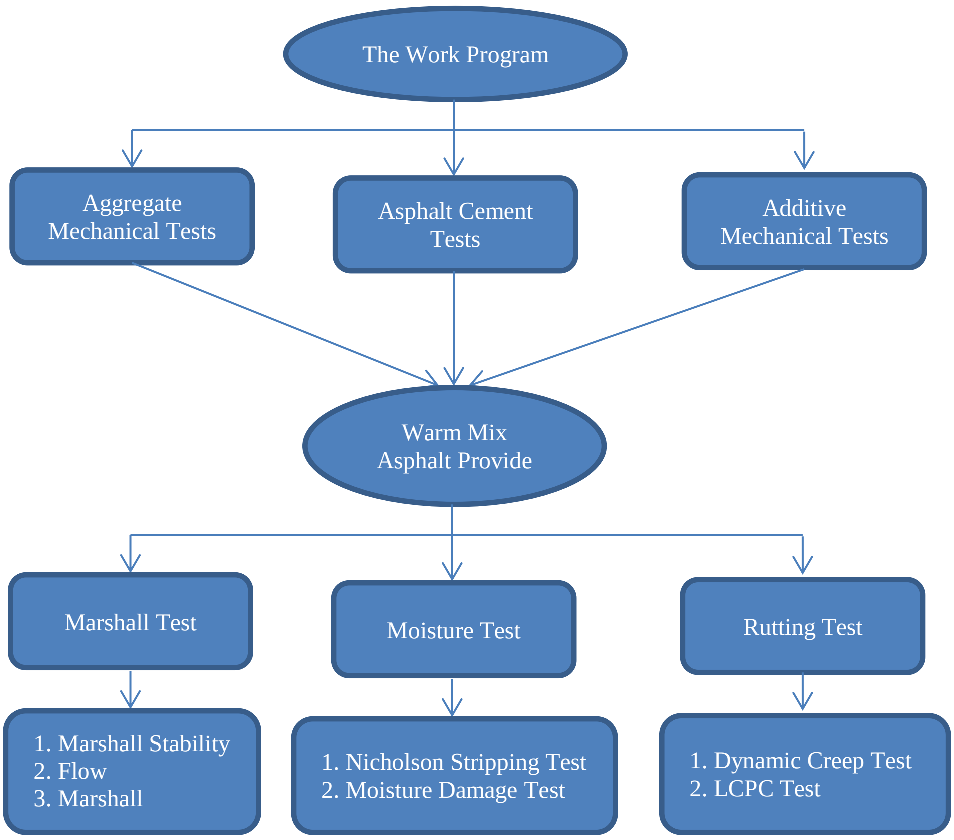

Figure 1. Research methodology

2. Materials and Methods

2.1. Applied Material

The aggregates used in the current study were extracted from a limestone obtained from a mine in the southern part of Trabzon province in Turkey. Filler was used to provide WMA mixtures from stone powder, which has been found to reduce moisture sensitivity in previous studies. Mechanical tests were adminstered to determine the quality of aggregates according to the common standards which are presented in Table 1.

Table 1. Mechanical properties of aggregates

Properties	Method	Requirement	Values
Water absorption %	ASTM C127 [25]	2.8 Max.	0.48
Los Angeles abrasion (%)	ASTM C131 [26]	30 Max.	18
Flat and Elongated	ASTM D 4791 [27]	20 Max.	12
Coarse aggregate specific density (g/cm^3)	ASTM C127 [25]	-	2.721
Fine aggregate specific density (g/cm^3)	ASTM C127 [25]	-	2.731
Mineral filer specific density (g/cm^3)	ASTM C127 [25]	-	2.741

The type of Asphalt cement in the current study was PG 64 -22, the properties of which are described in Table 2.

Table 2. Physical properties of PG 64 -22

Properties	Method	Requirement	Values
Penetration (0.1 mm)	EN-1426 [28]	-	58
Softening point (R&B) (°C)	EN-1427 [29]	-	50.2

Table 3 presents the physical properties of bentonites used in the current study.

Table 3. Physical properties of Bentonite

Gs	LL	PL	PI
2.233	165	43	122

Table 4 illustrates the Fatty Arbocel used in the current stud.

Table 4. Properties of Fatty Arbocel

Properties	Values
Fiber length (mm)	2> and <5
Fiber thickness (mm)	2
Bulk density (g/cm^3)	410-440
Flash point (°C)	>300

2.2. Samples Provided

To determine optimum bitumen content according to the Marshall method, three samples were prepared for each asphalt concrete containing 4, 5.4, 5, 6 and 6.5% bitumen. To make WMAs, the aggregates were heated at 135° C for 24 hours. Bitumen was heated up to 130° C to determine the optimum bitumen percentage mixture. Furthuremore, Marshall hammer was performed on both sides of compacted Specimens of 75 impacts to stimulate heavy traffic. The optimum amount of bitumen content (OBC) for the WMAs was also determined 5.8 %. Next, the amounts of bentonite additives which were 1, 3, 5, 7 % of the total weghit of OBC were added to the mixture, and finally the fatty Arbocel fiber which was 0.3 % of total sample weight was combined.

Figure 2. Marshall Specimens

2.3. Marshall Test

The Marshall quotient indicates the rigidity of the asphalt mixture. Any increase in the ratio i, increases the rigidity and resistance of the mixture against permanent deformations. Thus, to estimate the ratio, the specimens are placed inside Marshall Jacket and pressurized to evaluate Marshall Stability and flow values [30].

Figure 3. Marshall Test

2.4. Moisture Damage Test

According to AASHTO T283-03 standard, a number of six samples were made, out of which three were used for indirect tensile strength test under dry conditions (unsaturated) and the remaining three samples were used for testing under saturated conditions.

$$\mathrm{ITS} = \frac{2\mathrm{Pmax}}{\pi \mathrm{Dt}} \tag{1}$$

Where;

ITS: the tensile strength (kpa), P: maximum load (N), t: specimen thickness (mm), D: the specimen diameter (mm).

$$\mathrm{TSR}\ \% = \frac{\mathrm{ITSwet}}{\mathrm{ITS\ dry}} \times 10 \tag{2}$$

As mentioned above, the minimum values of TSR for resistance against water damages should be equal to 75% [31].

Figure 4. Moisture Damage Test

2.5. Stripping Test

Nicholson stripping test was carried out to determine the resistance of bitumen against separation of aggregates due to the water effect. The adhesion between the aggregate and asphalt cement plays an important role in increasing the resistance of asphalt mixture against permanent deformation which consequently increases its durability [32].

Figure 5. Nicholson Stripping Test

2.6. Dynamic Creep Test

It is an experiment to measure permanent deformations hat occur in asphalt concrete under the influence of repeated loads. During dynamic creep test, the specimens are subjected to a uniaxial compressive load at a specified period. After repeating each load, permanent deformations in the samples are measured [33].

$$\mathcal{E}c = 3n - L1)/G \quad (3)$$

$$\mathcal{E}r = (L2 - L3)/[G - (L3 - L1)] \quad (4)$$

$$\sigma = F/A \quad (5)$$

$$Ec = \sigma/\mathcal{E}c \quad (6)$$

$$Er = \sigma/\mathcal{E}r \quad (7)$$

Where;

$\mathcal{E}_c$: Plastic deformation, $\mathcal{E}_r$: Elastic deformation, E_c: Creep module, E_r: Elastic module, σ: Stress (kPa)

Figure 6. Dynamic Creep Test

2.7. LCPC Rutting Test

In order to perform a French rutting test, slab-shaped specimens with a length of 500 mm and a width of 180 mm and a height of 50 mm are prepared for each WMA mixture. The measurements are performed at 1000, 3000, 5000, 10,000, 30,000 and 50,000 rpm. Finally, using equation, the amount of rutting settlement is determined for each mixture (8), [34].

$$Y = A[N/1000]^{B} \tag{8}$$

Where;

Y: N cycle settlement (mm), A: settlement at 1000 rpm, B: It is the slope of the linear line in logarithmic coordinates.

Figure 7. LCPC Rutting Test

3. Results and Discussion

3.1. Marshall Test

The results of Marshall Quotient test are given in Figure 8, which presents the improvement of samples' Marshall Quotient with the addition of nano-bentonite. This was due to the improvement in the properties of bitumen modified with nano-bentonite as a result of high specific surface area of nano-particles. The viscosity and adhesion of modified bitumen have been increased by increasing the amount of nano-bentonite. Furthermore, fatty arbocel helps the adehesive property between bitumen and aggregates. So, it can be said that using the nano-bentonite and fatty arbocel can improve the resistance of WMAs against permanent deformations. The results are in line with the results of the Iskender E. experiments [10]. The results show that Marshall Quotient increased by 2.79, 8.7, 11.4 and 15.6 % compared to conventional mixture.

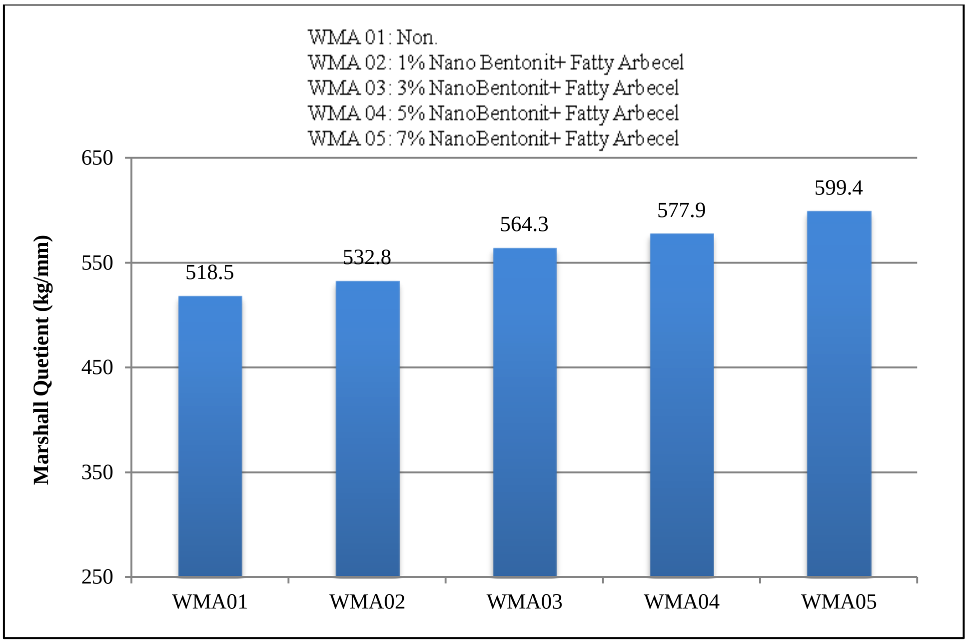

Figure 8. Marshall Quotient test results

3.2. Nicholson Stripping Test

The results of Nicholson stripping tests are given in Figure 9.

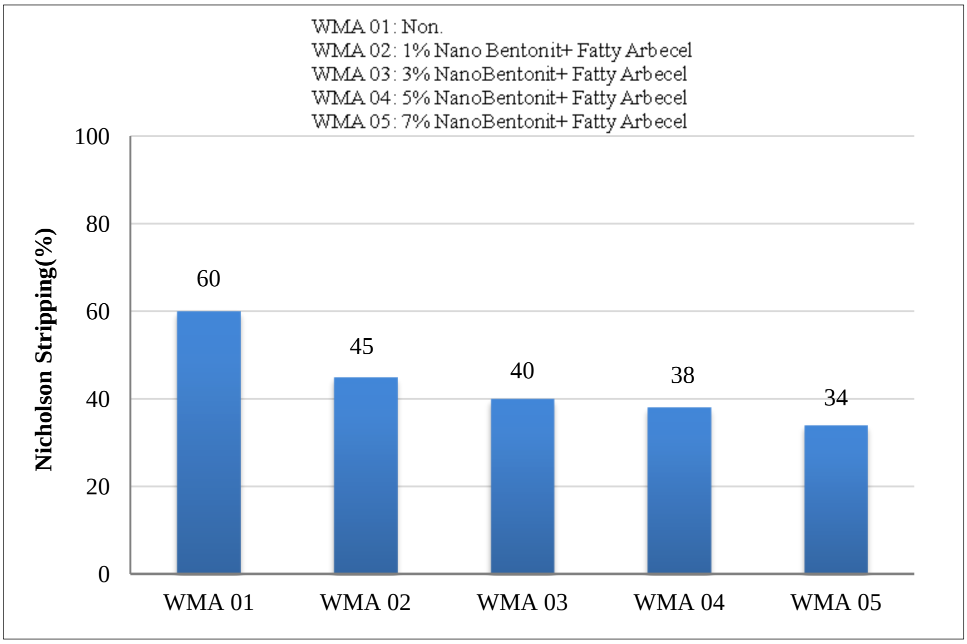

Figure 9. Results of Nicolson stripping test

Figure 9 reveals that adding 0.3 % of fatty Arbocel to the mixture and increasing the amount of nano-bentonite (1, 3, 5 and 7) increases the resistance of WMAs in comparison to none additive WMAs which showed 33%, 40%, 67%, 75% increase. It is clear from the data that the additives significantly affected the adhesion property of asphalt cement and improved its resistance against stripping. Hence, it is suggested that WMAs modified with nano-bentonite and fatty Arbecol are very useful in the performance of them against stripping, especially in cold and wet regions.

3.3. Moisture Damage Test

The Indirect tensile strength (ITS) values of WMAs are presented in Figure 10. As shown, nano-bentonite together with Arbocel increases the tensile strength of the saturated and unsaturated samples.

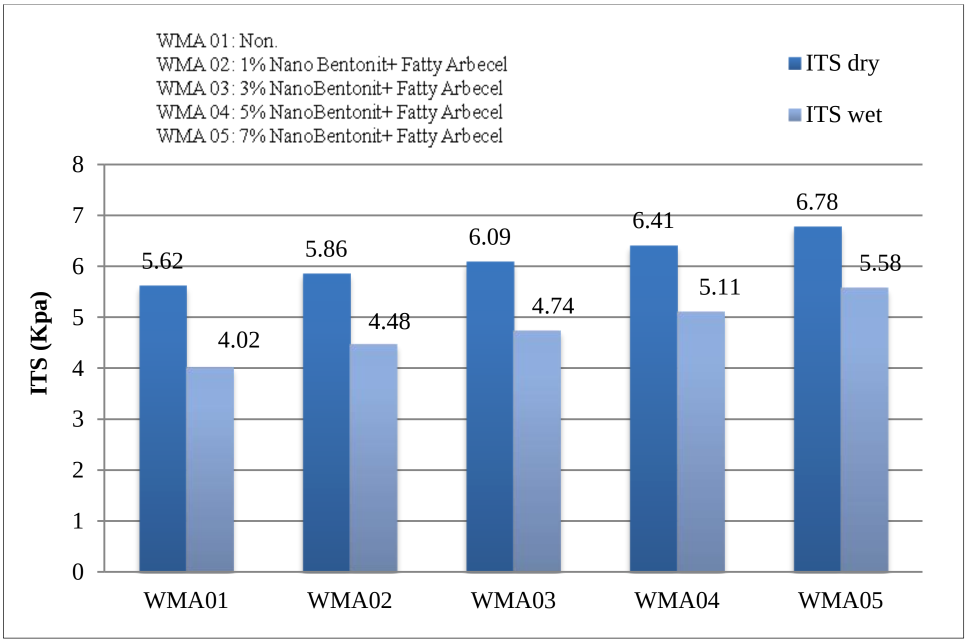

Figure 10. Results of ITS test

It is observed that the ITS value of the saturated mixtures are lower than that of dry mixtures, due to the presence of water in the mixture resulting in reduced adhesion between the aggregates and bitumen leading to a reduction in the strength of the asphalt mixture samples under the loads. Nano-bentonite improves the elastic properties of bitumen and polymer and Arbocel improves the elastic properties of the mixture. Therefore, the combined application of these additives can play an important role in increasing the tensile strength of WMAs and compensate for the weakness of these mixtures against moisture damages.

The TSR results in Figure 11 show that the samples containing the additives were able to pass the standard criteria, wheras the non-additive samples remained below the criteria specified for the TSR. Anti-stripping properties of nano-bentonite and Arbocel increase the TSR of modified mixtures. According to the results presented in Figure 11, the highest amount of TSR occurs in samples containing 0.7% nano-bentonite and 0.3 % fatty Arbocel, indicating that as the percentage of nano-bentonite increases, the adhesion to the semi-hot asphalt mixtures also increases. Anti-stripping properties of additives causes the mixture to resist higher moisture compared to other samples during frost and thaw cycles. Thus, it is apparent that the additive increases the resistance of the mixtures against moisture damage. These results are in line with the results of Ameri M. experiments [35].

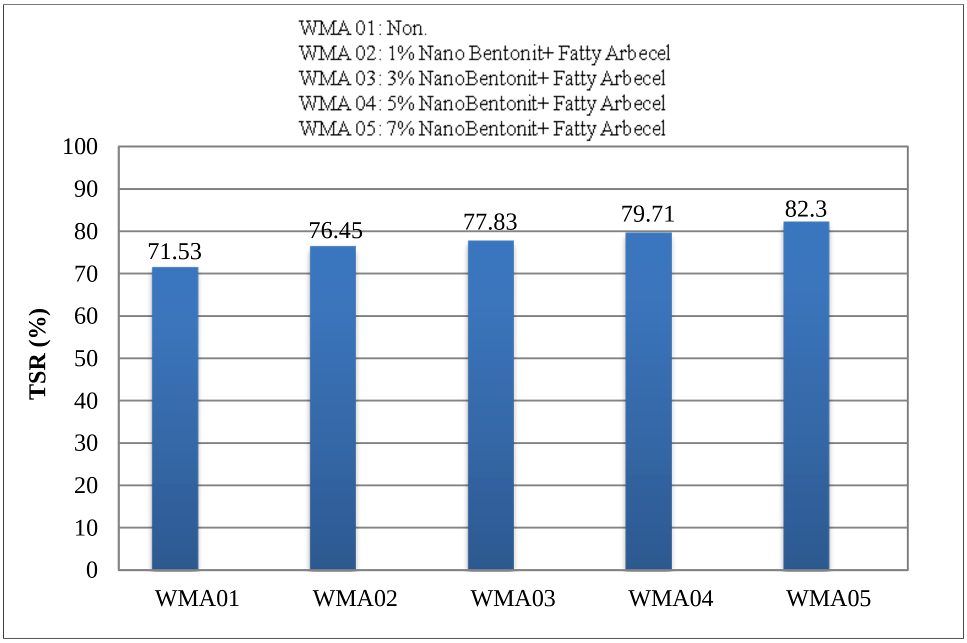

Figure 11. Results of TSR

3.4. Dynamic Creep Test

Dynamic creep test was applied to measure WMAs deformations the results of which are shown in Figure 12.

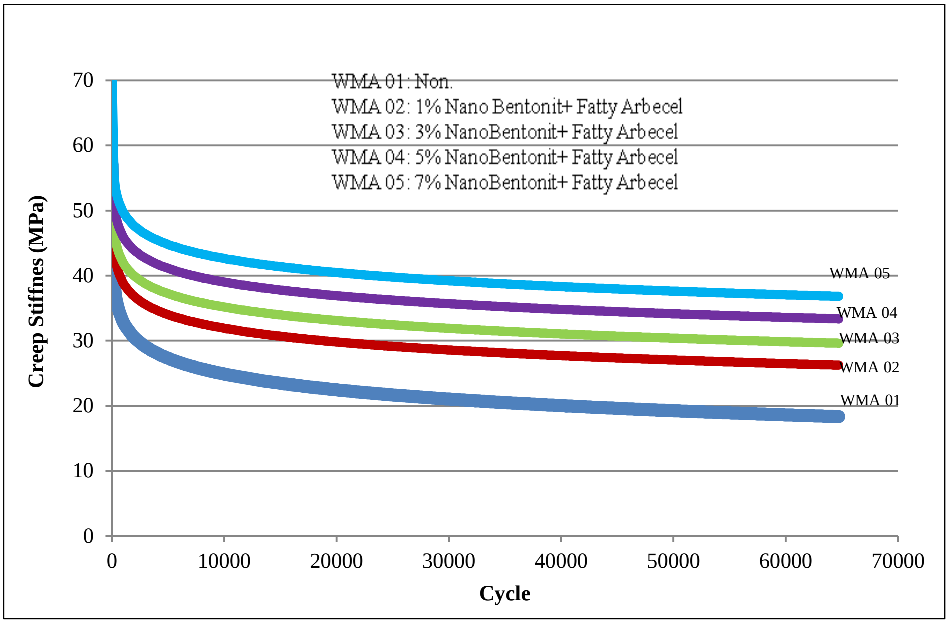

Figure 12. Creep Module Diagram

According to the results, there was a decrease in WMAs with nano-bentonite and Fatty Arbocel compared to the mixtures without additives. Mixtures containing nano-bentonite Arbocel exhibit lower creep modulus in the same cycle than the control mixture, indicating greater plastic deformation in the control mixture. It is suggested that the addition of nano-clay with arbesol strengthen WMAs against deformation compared to conventional WMAs. As a result, Nano-bentonite and arbocel with improved adhesion between aggregate and bitumen can improve the creep performance of WMAs and rutting potential. The results also suggest that, in mixtures containing nano-benonite and Arbocel, the hardness increased and these mixtures showed higher resistance against rutting compared to non-additive WMAs. Hence the modified mixture is claimed to have more service life than none modified mixture.

3.5. LCPC Rutting Test

LCPC rutting testing was used to measure the depths of the rut. As shown in Figure 13, the addition of arbesol and nano-bentonite decreases the depth of the rut.

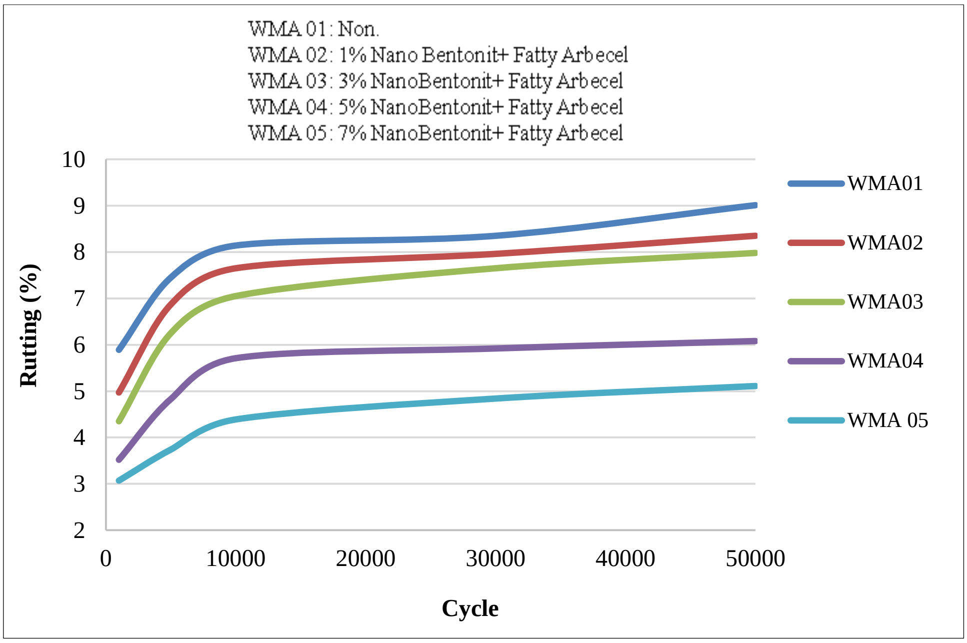

Figure 13. Results of LCPC Rutting test

Rutting test was performed on slab form samples. According to the proposed standard for LCPC method, the amount of rutting caused by 30,000 wheel cycles, is expected to be not bigger than 6%. According to the curve in Figure 13, it is apparent that samples containing 1, 3 and 5% nano bentonite did not reach the standard limit. By increasing the amount of nano bentonite, not only we could reach the reach the standard limit, but also we were successful in reducing the rutting percentage of samples containing 7% nano-bentonite and 0.3% fatty Arbocel about one second compared to non-additive samples. These results are in line with the results of the Ziari H. experiments [36]. Given the comparative rutting curves, it is clear that the application of fatty Arbocel fibers and nano-bentonite reduces the rutting time compared to non-additive samples. According to the curve, samples containing 7% nano-bentonite and 0.3% fatty Arbocel represented the best results which can yield important achievements in roads with heavy vehicle traffic.

4. Conclusions

- Usage nano-bentonite and fatty Arbecol as additives to WMAs has a significant effect on the Marshall Quotient of these mixtures compared to non-modified mixtures. The results show that Marshall Quotient was increased by 2.79, 8.7, 11.4 and 15.6 % compared to conventional mixtures. So, it is suggested that using the nano-bentonite and fatty arbocel can improve WMAs resistance against permanent deformations.

- The values obtained from Nicholson stripping tests revealed that nano-bentonite and fatty Arbecol additives were effective on the adhesion between aggregates and bitumen. Hence, it is suggested that WMAs modified with nano-bentonite and fatty Arbecol are very useful in their performance against stripping, especially in cold and wet regions.

- Nano-bentonite and Fatty Arbocel increase the resistance of WMAs against moisture damages, According to the results, the highest amount of TSR occurs in samples containing 0.7% nano-bentonite and 0.3 % fatty Arbocel. Due to its lower cooking temperature in the preparation process which consequently increases the mixture's moisture sensitivity. The use of nano-bentonite and Fatty Arbocel additives can have a very effective role against the functional weakness caused by moisture sensitivity.

- According to the results of the dynamic creep test, both the resistance of modified WMAs against permanent deformation and the amount of elastic deformation revealed an increase. The highest creep modulus value was obtained by mixing 7% nano-bentonite and 0.3% fatty Arbecol. The results also revealed that in mixtures containing nano-benonite and Arbocel, mixtures hardness increased. Also, these mixtures had higher resistance against rutting compared to non-additive WMAs.

- According to the results of the LCPC rutting test, application of fatty Arbocel fibers and nano-bentonite reduces the rutting process when compared to non-additive samples. Increasing the amount of nano bentonite to the reach standard limit, the rutting percentage of samples containing 7% nano-bentonite and 0.3% fatty Arbocel decreased about one second compared to non-additive samples. It is clear that nano-bentonite and fatty Arbecol can help the performance of WMAs and improve their life span.

5. Conflicts of Interest

The authors declare no conflict of interest.

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