Rutting Performance of Asphalt Mixtures with Nanotube-fibres at Varied Addition Rates

Haya Almutairi, M.Sc.
Ph.D. Candidate
University of Waterloo
Waterloo, Ontario

Peter Mikhailenko, Ph.D.
Research Associate
University of Waterloo
Waterloo, Ontario

Hassan Baaj, Ph.D., P.Eng.
Associate Professor
University of Waterloo
Waterloo, Ontario

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ABSTRACT

The limiting factor for the service life of asphalt pavements in many cases is the damage associated with cracking and rutting. Moreover, severe rutting can not only affect the service life, but also affect the safety of the road. The introduction of fibres has been shown to enhance the crack resistance of asphalt pavements. This study will investigate a new type of nanotube-fibres that would allow for better performance of the asphalt mixture at higher temperatures. The main innovation with the nanotube-fibres is their expansion and contraction properties at low and high temperatures, respectively. The performance of Hot Mix Asphalt (HMA) with fibres of 25-mm length at three different addition rates was examined and compared with control samples without fibres. The performance testing was conducted using the Hamburg Wheel Tracking Test at 50°C, which is a measure of the rutting susceptibility of asphalt at higher temperatures. The performance of the asphalt with nanotube-fibres under these conditions was evaluated and recommendations made on its use in the field, along with further research needs.

RÉSUMÉ

Le facteur limitant de la durée de vie des chaussées en asphalte est souvent lié à la fissuration et à l'orniérage. En outre, un orniérage excessif peut non seulement affecter la durée de vie, mais également la sécurité de la route. Il a été démontré que l'ajout de fibres améliore la résistance à la fissuration des chaussées en asphalte. Cette étude examinera un nouveau type de fibres de nanotubes permettant une meilleure performance du mélange d'asphalte à des températures plus élevées. La principale innovation avec les fibres de nanotubes réside dans leurs propriétés de dilatation et de contraction aux basses et hautes températures, respectivement. La performance d'un enrobé à chaud (HMA) avec des fibres de 25 mm de longueur à trois taux d'addition différents a été examinée et comparée à celle d'échantillons témoins sans fibres. Les tests de performance ont été réalisés à l'aide du test « Hamburg Wheel Tracking » à 50°C, qui est une mesure de la sensibilité à l'orniérage des enrobés à des températures plus élevées. La performance de l'enrobé contenant des fibres de nanotubes dans ces conditions a été évaluée et des recommandations ont été formulées sur son utilisation sur le terrain, ainsi que sur d'autres besoins de recherche.

1.0 INTRODUCTION

Over the last few years, nanotechnology has received increased attention and been incorporated into many fields, and more recently to asphalt pavements. Various nanomaterials have been used to modify asphalt binders and mixtures. Nanotechnology is defined as technology that includes the design, construction, and utilization of functional structures with at least one characteristic dimension at the nanometer scale [1]. The use of nanotechnology does not simply mean working with small dimensions. Rather, it involves taking advantage of the unique physical, chemical, mechanical, and optical properties of materials at this scale. The morphological features of nanoscale dimensions result in some special properties, such as large specific surface areas, high surface free energy and effective dispersion [2]. Moreover, nanomaterials have the potential to create effective bridges between bulk materials and atomic/molecular structures [3]. A wide range of nanomaterials can be used to modify asphalt binders for the construction and maintenance of road pavements, such as nano-sized hydrated lime, nano-sized plastic powders or polymerized powders, nanoclay, nanosilica, nanotubes and nanofibres [4].

Generally, nanotechnology has significant benefits in terms of making processes and products increasingly efficient, durable, and cost effective [5]. Many benefits of the use of nanomaterials in asphalt pavements have been identified [3]. It was found that nanomaterials can improve the low-temperature performance of asphalt mixtures, the durability of asphalt pavement, and the storage stability of polymer-modified asphalt. Additionally, nanomaterials can enhance a pavement’s resistance to aging and decrease its susceptibility to moisture [4].

Although nanotechnology is considered to be relatively new in the field of civil engineering, many researchers have studied the potential benefits of adopting this technology for cement-based materials [6] and polymer composites [7, 8]. However, relatively few recent studies have been conducted in the area of asphalt binders and mixtures. Even fewer studies include investigations into the behaviour of asphalt binders and mixtures when nanotubes are added. Santagata et al. [9] evaluated the rheological characteristics of bituminous binders blended with different percentages of Carbon Nanotubes (CNT) under different aging conditions using viscosity and Dynamic Shear Rheometer (DSR) tests. Their results showed that the rheological properties are highly affected when high percentages of CNT are added to asphalt binder. CNTs can improve rutting and thermal cracking performance. Also, their lower susceptibility to oxidative aging is expected to have a positive impact on the long-term performance of the asphalt pavement. In the same manner, other studies showed an improvement in the rutting resistance of carbon nanofibre-modified binder when tested using DSR and viscosity tests [10-12]. Despite the added cost of adding carbon nanotubes to asphalt binder, they can improve asphalt pavement properties and, thus, decrease thickness of under layers, leading to reductions in stone material consumption. Finally, Saliani et al. [13] concluded that adding Aramid short fibres can improve the durability and tensile strength at low temperatures of asphalt mixtures. Moreover, they found that better interlock between the components was attained when short fibres were used.

2.0 OBJECTIVES AND SCOPE

The objective of this study was to investigate the performance of Hot Mix Asphalt (HMA) with nanotube-fibres of 25mm length at higher temperatures and at three different addition rates (110, 138, and 165 g/ton) and compare the results versus control sample without fibres. The high temperature performance was investigated using the Hamburg Wheel Tracking Device (HWTD) at 50°C, which is a measure of the rutting susceptibility of HMA.

3.0 LABORATORY EXPERIMENTS

3.1 Materials

In this study, PG 58-28, which is considered the most commonly used asphalt binder in Southern Ontario, and Hot Laid 3 (HL3) asphalt mix was collected from Capital Paving Inc. The HL3 mix consisted of 47 percent crushed gravel, 43 percent asphalt sand, 10 percent blend sand, and 5.1 percent PG 58-28 asphalt cement. Table 1 presents the gradation of the aggregate used in this study.

Table 1. Hot Laid 3 (HL3) Aggregate Gradation

Sieve Size (mm)	Percent Passing by Mass (%)
26.5	100
19.0	100
16.0	100
13.2	99.7
9.5	83.9
4.75	53.3
2.36	47.7
1.18	41.0
0.600	30.4
0.300	14.5
0.150	5.3
0.075	3.4

Figure 1 shows the nanotube-fibres (Acro-Bind) used in this study, which is a blend of aramid, bituminous oils, and minerals formulated to provide multi-dimensional reinforcement to asphalt mixtures. These nanotube-fibres are heat resistant with a flash point of 220°C, which makes them ideal for HMA mixing and compaction temperatures. Moreover, the main innovation in these nanotube-fibres is their expansion and contraction properties at low and high temperatures, respectively.

3.2 Sample Preparation and Volumetric Properties

A control mix was prepared according to the HL3 mix design requirements, at a mixing temperature of 145°C. To prepare the mixtures with nanotube-fibres, the aggregate was heated in the oven at 145°C. Then, the required dose of nanotube-fibres was added to the mixer containing the heated aggregates, and mixed for 10 seconds until good distribution was attained. In this respect, it is important to highlight that the mixtures with the 110 g/ton dosage presented best visual distribution among the mixtures that contained fibres. After mixing the nanotube-fibres and aggregate for 10 seconds, the asphalt binder was added and mixed for 90 seconds. The mixing time was chosen to prevent the filaments from clustering. Three different lengths of nanotube-fibres were used (13, 20, and 25 mm) and at three different addition rates of 110, 138 and 165 g/ton. Table 2 shows all different nanotube-fibres dosages and their corresponding mix names.

Cylindrical HMA samples were fabricated using the Superpave gyratory compactor, shown in Figure 2, at the Center of Pavement and Transportation Technology (CPATT) laboratory with 7 ± 2 percent air voids. For each mixture, four HWTD specimens were prepared and tested.

Figure 1. The nanotube-fibres (Acro-Bind) used in this study.

Table 2. Mixture Matrix of Fibre Length and Dosage

Mixture	Nanotube-Fibre Content	Mix Label
Control Mix	0	HL-3
HMA + 13mm Nanotube-fibres	110 g/ton	HL-3-13-110
	138 g/ton	HL-3-13-138
	165 g/ton	HL-3-13-165
HMA + 20mm Nanotube-fibres	110 g/ton	HL-3-20-110
	138 g/ton	HL-3-20-138
	165 g/ton	HL-3-20-165
HMA + 25mm Nanotube-fibres	110 g/ton	HL-3-25-110
	138 g/ton	HL-3-25-138
	165 g/ton	HL-3-25-165

Figure 2. Superpave Gyratory Compactor

The asphalt mixture samples were compacted to the same height of 63 mm and mass of 2.51 kg. Theoretical maximum specific gravity (G_{mm}) values, determined from loose mixture based on ASTM D 2041 [14], were found for each mixture. As the addition of nanotube-fibres has a relatively small impact on the G_{mm} values, the asphalt content for the control mix was used for all mixtures. Although the rutting performance for only one nanotube-fibre size is presented in this paper, a detailed evaluation of the volumetric properties for different nanotube-sizes was conducted to see the effect of the nanotube-fibres in the mixtures. Detailed volumetric properties of different mix types are presented in Table 3.

The air voids for all samples were between 7.07 and 8.41 percent, which is within the acceptable range as defined by the standard. Only three samples, HL-3-25-138, HL-3-25-165, and the HL-3-13-138, had higher air voids compared to the Control sample. However, for all other samples, the air voids were less than the Control samples as shown in Figure 3, despite all samples having the same mass and being compacted to the same height. In this respect, comparing Voids in the Mineral Aggregate (VMA) for different mixes is irrelevant since VMA is a very important mix design parameter only at a target air voids content.

Due to the low fibre content (0.01 to 0.02 percent), the apparent density of the mixture was assumed not to change noticeably with their addition, so the G_{sb} was assumed to be 2.695. The fibre mixes had a similar or slightly higher effective asphalt content values compared with the Control mix as shown in Figure 4. This may indicate that higher nanotube-fibres contents do not have the binder absorption issues found with other types of fibres used previously [15]. The slight increase may be attributed to variability in the testing of the maximum theoretical specific density (G_{mm}). The G_{mm} values were obtained for all mixtures, where it was noted that separating the particles of the mixtures with fibres was especially difficult, which could have contributed to the variability in the G_{mm} and air voids. It can also be observed that the presence of nanotube-fibres produces an increase in the cohesion between the aggregate particles of the loose mixture. Figure 5 shows the loose mixture with fibres when conducting the G_{mm} testing.

Table 3. Volumetric Properties of the Mix Types Evaluated

Mix Type	AC, %	G_{mm}	G_{mb}	Air Voids, %	G_{se}	VMA, %	VFA, %	Pba, %	Pbe, %
Control Mix	5.1	2.521	2.321	7.93	2.737	18.28	56.59	0.575	4.554
HL-3-13-110	5.1	2.506	2.315	7.62	2.718	18.49	58.77	0.319	4.797
HL-3-13-138	5.1	2.52	2.314	8.17	2.735	18.52	55.87	0.558	4.571
HL-3-13-165	5.1	2.521	2.339	7.22	2.737	17.64	59.08	0.575	4.554
HL-3-20-110	5.1	2.506	2.314	7.66	2.718	18.52	58.64	0.319	4.797
HL-3-20-138	5.1	2.504	2.327	7.07	2.716	18.07	60.87	0.285	4.830
HL-3-20-165	5.1	2.5	2.317	7.32	2.711	18.42	60.26	0.216	4.895
HL-3-25-110	5.1	2.5	2.322	7.12	2.711	18.24	60.97	0.216	4.895
HL-3-25-138	5.1	2.52	2.308	8.41	2.735	18.73	55.10	0.558	4.571
HL-3-25-165	5.1	2.516	2.31	8.19	2.731	18.66	56.13	0.490	4.635

Note: AC is Asphalt Cement Content, Gmb is the Bulk Specific Gravity of the mixture, Gmm is the Maximum Theoretical Specific Gravity of the mixture, Gse is the Effective Specific Gravity of the aggregates, Pba is the Absorbed Asphalt Content, Pbe is the Effective Asphalt Content, VFA is Voids Filled with Asphalt, and VMA is Voids in the Mineral Aggregate.

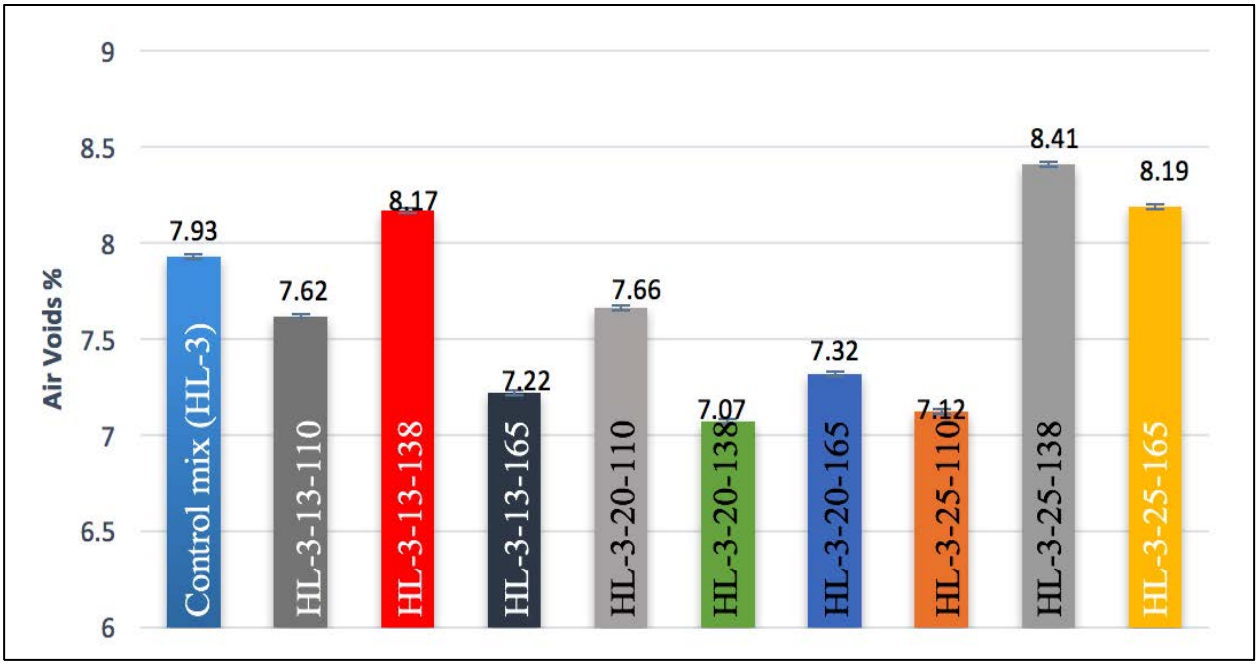


Figure 3. Air Void Content of Hot Mix Asphalt Specimens

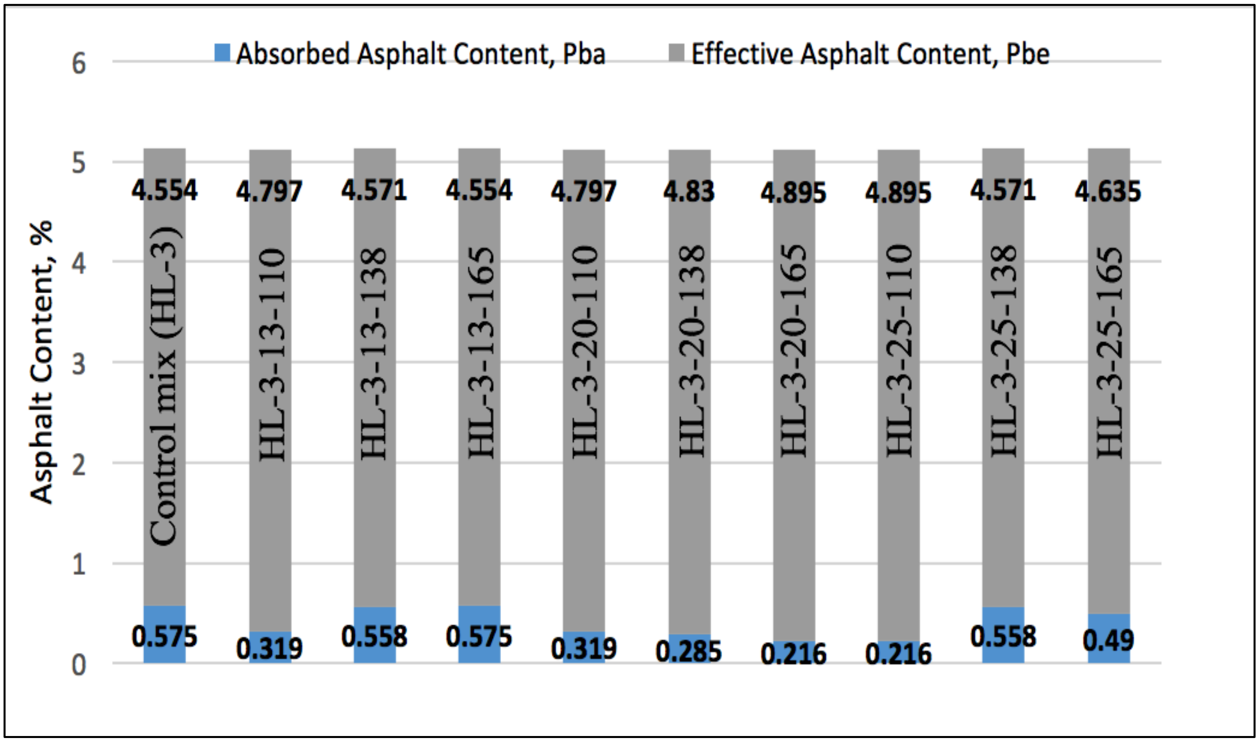


Figure 4. Absorbed and Effective Asphalt Content of Hot Mix Asphalt Specimens

Figure 5. Loose mixture with fibres when preparing the Maximum Theoretical Specific Gravity (Gmm) testing.

3.3 Hamburg Wheel Tracking Device Testing

To evaluate the rutting and moisture susceptibility of compacted specimens, the CPATT HWTD (Figure 6) was used in in accordance with AASHTO T324-11 “Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)” [16]. The device tracks a 158 lb (705 N) load rubber wheel across the surface of Superpave gyratory compacted specimens submerged in a hot water bath at 50°C for 10,000 cycles, with each cycle consisting of two passes.

During the test, the deformation of the specimens is recorded as a function of the number of passes. Measurements were taken each 50 wheel passes until 1,200 wheel passes. After that, the measurement was taken after each 2,000 wheel passes until 20,000 wheel passes. Although four samples were tested each time, a measurement represented the average rut depth of two adjacent samples as shown in Figure 7.

4.0 RESULTS AND DISCUSSION

The overall rutting performance of the mixture with 25-mm nanotube-fibres was better than the Control mixture as shown in Figures 8 and 9. Despite the fact that the samples appear to have a slightly higher air void content, they seem to perform better than the Control in terms of rutting. This could be due to the better reinforcement effect at this particular nanotube-fibre size. Even with at the smallest nanotube-fibre content, the rutting resistance of the asphalt mixture is improved. In this case, adding the 110 g/ton of nanotube-fibres content has given the best improvement to the mixture in terms of rutting. However, it should be noted that higher dosages (135 and 165 g/ton) have also led to an improvement of the rutting resistance, but the results show a higher variability compared to the Control mixture and to the 110 g/ton sample (Figure 10). This may be due to a non-homogenous distribution of the fibres during laboratory mixing. This phenomenon could be remedied in plant conditions due to the larger scale of the mixing equipment.

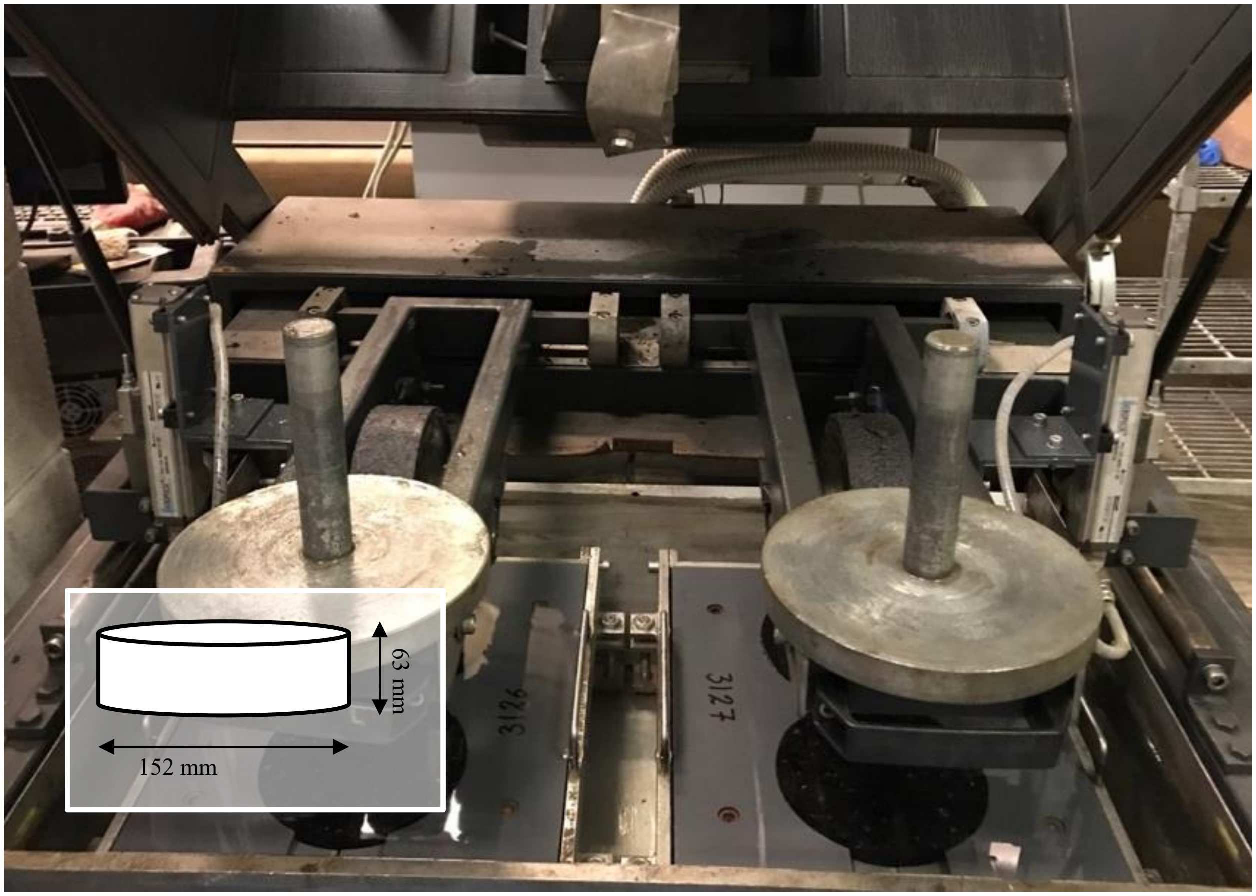
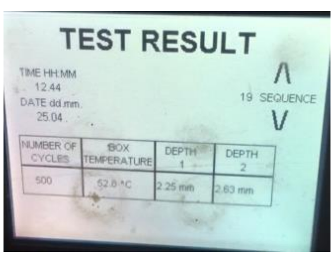


Figure 6. Hamburg Wheel Tracking Device

DEVICE SCREEN



Depth 1 = the average rut depth for sample A & B
Depth 2 = the average rut depth for sample C & D

Figure 7. Measurements represented in the Hamburg Wheel Tracking Device (HWTD) screen.

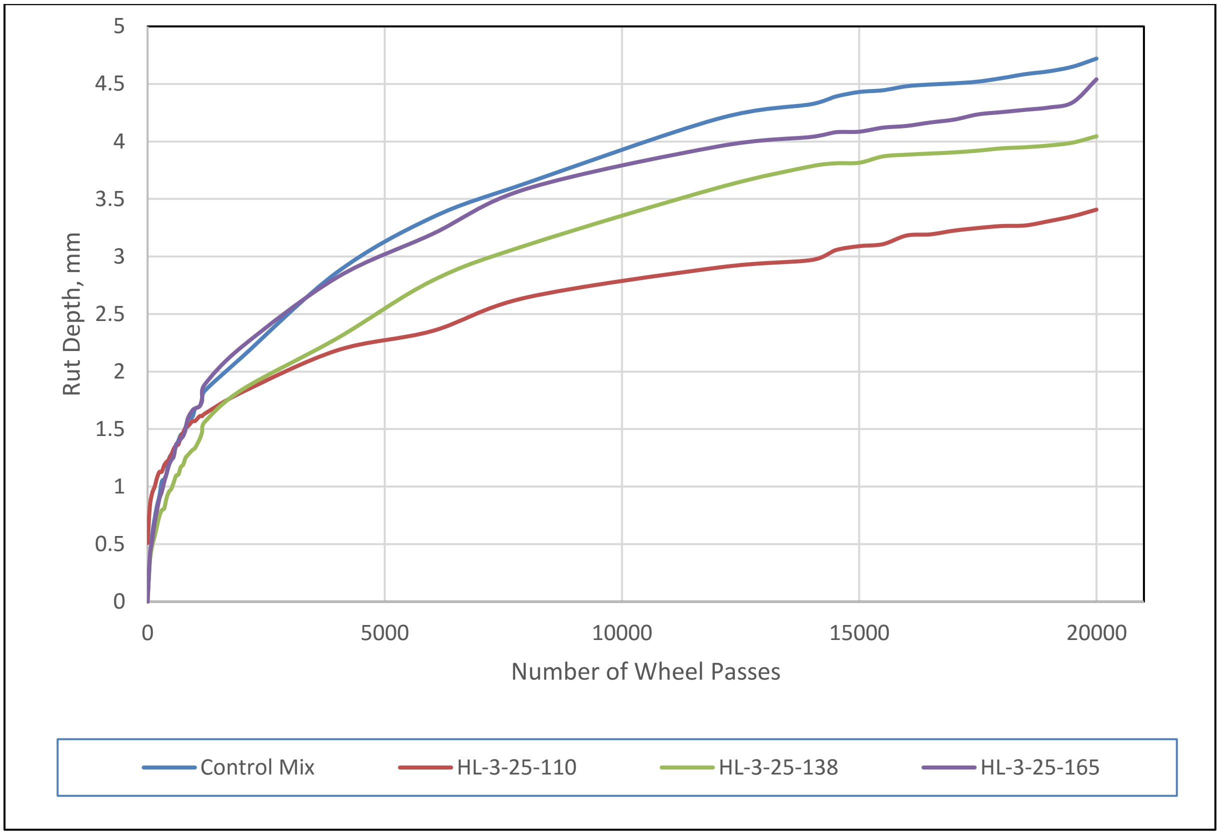


Figure 8. Hamburg Wheel Tracking Device (HWTD) test results of Control Hot Mix Asphalt (HMA) mix and HMA mixtures with 25-mm nanotube-fibres.

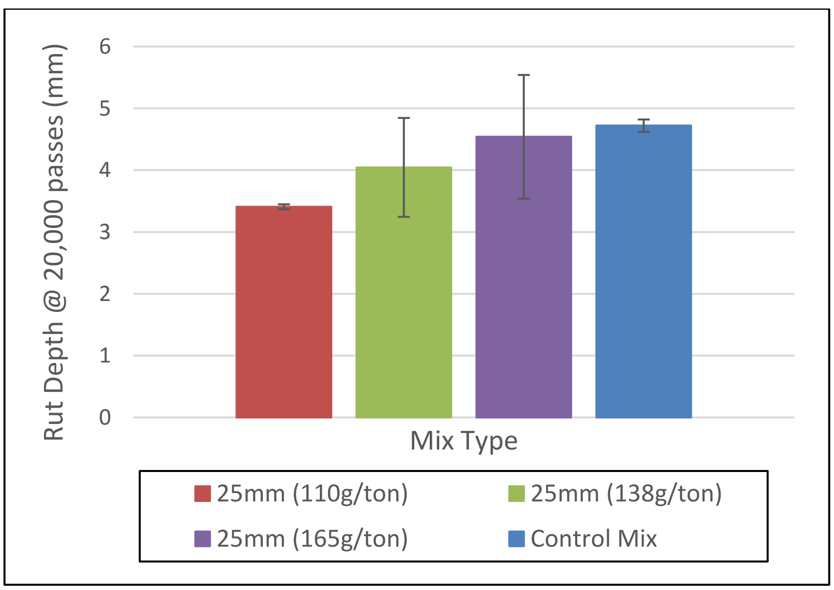


Figure 9. Standard deviation for Hamburg Wheel Tracking Device (HWTD) test results of Control Hot Mix Asphalt (HMA) mix and HMA mixtures with 25-mm nanotube-fibres.

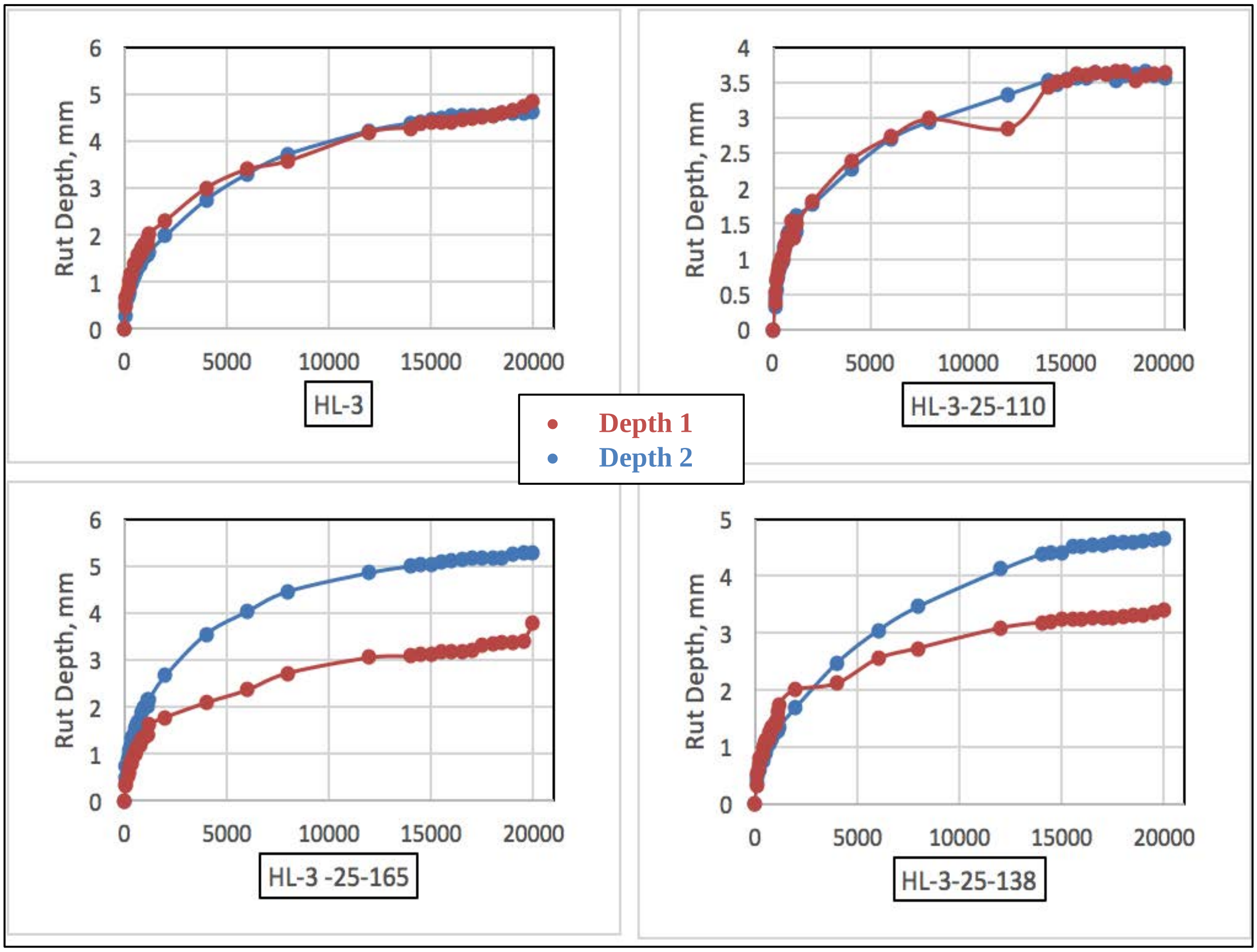


Figure 10. Rut depth measurements obtained from Hamburg Wheel Tracking Device (HWTD) test results of Control Hot Mix Asphalt (HMA) mix and HMA mixtures with 25-mm nanotube-fibres.

In addition, the determination of the optimum fibre content in the mixture needs to be based on a balanced mix design approach considering other performance criteria, such as fatigue and thermal cracking. The use of the nano-tube fibres is expected to improve both performance criteria in addition to improving the ductility of the asphalt mixture and then increasing service life of the pavement.

As mentioned earlier, the rut depth measurements obtained from HWTD represent the average rut depth for two samples. Thus, the two measurements were plotted separately to understand the rutting behaviour of different mixes. In Figure 10, the results were consistent for all the four tested samples for the Control mix and mostly for the HL-3-25-110. On the other hand, the difference in the results of two depths increased with the increase of the nanotube-fibre content in the mix. This difference can be attributed to the difference of the nanotube-fibre distribution in the mixture. These results indicate that 10 seconds mixing time was sufficient for the HL-3-25-110 mix to achieve a homogenous mix which resulted the lowest variability in the results. However, more mixing time could improve the nanotube-fibre distribution for higher fibre contents.

5.0 CONCLUSIONS

This study evaluated the performance of asphalt mixtures with nanotube-fibres at three different addition rates (110, 138 and 165 g/ton) using the Hamburg Wheel Tracking Device (HWTD) and compared them with control samples without nanotube-fibres. The results indicate that the rutting resistance can be improved up to 65 percent by adding nanotube-fibres of 25-mm length to asphalt mixtures.

Furthermore, 10 seconds of mixing time in the laboratory can provide good distribution of nanotube-fibres at 110 g/ton. In order to choose the best mixing time for the different fibre contents, it is recommended to investigate the fibres distribution using CT-scanning [17]. Additionally, the fibres did not appear to absorb the asphalt, with the effective asphalt, VMA, and VFA values remaining relatively steady for all the mixes. The cohesion in the mixture also appeared to increase, but this also made accurately obtaining the G_{mm} and air voids values more difficult, leading to variations in the results.

This study addressed the question of whether and to what extent the addition of fibres can improve the rutting resistance of asphalt mixtures. Additional performance testing such as thermal cracking and fatigue cracking is needed to evaluate asphalt mixtures containing different rates of nanotube-fibres. It is expected that asphalt pavement resistance to cracking would highly benefit from the unique behaviour of the nanotube-fibres in terms of expansion and contraction properties, and is the next step of the current study.

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