

Engineering Properties of Waste Plastic and Nanomaterials Modified Asphalt Mixtures

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Abstract

Stone Mastic Asphalt (SMA) has shown an extraordinary contribution in pavement engineering research and industry. Due to the climate changes and load conditions differences, using specific additives in SMA is essential. Therefore, it is vital to utilize a modern mixture with a high capacity to survive the high traffic loads. The current study aims to use the combination of waste HDPE and Nano-silica (NS) and waste polymer as a newly developed hybrid additive in SMA modification, which could improve the rutting and stiffness performance. By using the dry mix process, waste high density polyethylene (HDPE) and NS were blended with the C320 bitumen binder to produce the SMA mixtures. The Nano silica was added to the C320 binder (2%, 4%, and 6% by weight of the binder). The engineering properties were assessed through the Marshall stability, Marshall flow, Marshall Quotient, wheel tracking test, and 4 points bending fatigue tests. The results indicated that the addition of 4% -6% nano-silica improve the rutting and stiffness performance of the modified SMA mixtures in comparison with the non-modified mixtures. Results revealed that mixtures modified with the hybrid additive of 4 HDPE- 6%NS have exceptional performance, in terms of better stiffness, rutting resistance and longer fatigue life.

Keywords: Nano silica, waste HDPE, hybrid additive, asphalt, Marshall stability, rutting depth, fatigue damage.

1. Introduction

Stone mastic asphalt (SMA) is an asphalt mixture of a skeleton of coarse aggregate and a binder rich mortar with as much as 6% to 8% liquid bitumen. SMA consists of crushed coarse mixture, crushed fine aggregate, asphalt binder, mineral filler, and a stabilizer such as cellulose, mineral fibers, or a polymer for the binder [1]. Figure 1 displays a view of a typical SMA mixture and conventional dense graded mixture. The image on the left shows a higher percentage of bitumen and fractured aggregate in comparison with the conventional hot mix asphalt shown in the right-hand image. As the figure illustrates, conventional dense graded mixture contains less bitumen content with a more uniform gradation of the aggregate particles.

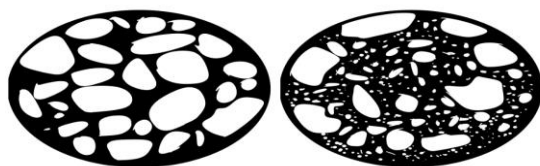


Figure 1: Typical SMA mixture (left) and dense graded mixture(right)

The strength and stability of the SMA is because of the stone portion of the coarse aggregate skeleton, which results in an increase in the internal friction rate and the resistance of the mixture to shear thereby enabling it to resist rutting and wearing out because of repetitive studded tyre contact. However, some weakness is distinguishable in the SMA structure, such as drain down, which ensues from the absence of mid-sized aggregate in the gap-graded mixture, which has a high asphalt binder content instead. In general, as the literature reveals, despite many advantages, such as high durability [2], improved resistance against fatigue and reflective cracking, and excessive rut resistance, less noise pollution of traffic and high skid resistance [3]. SMA mixtures also suffer from some disadvantages including delays in opening the roads to traffic, drainage of the binder, and higher initial costs. Due to the gap-graded nature of SMA mixes and the high bitumen content, they need stabilization and improvement to control bitumen drain-down [4]. To achieve this feature, polymer modifiers or fibers need be added to the SMA mixes to bring about the desire

modification, reinforcement, and stabilization in the mixture. Various kinds of polymers have been used to modify SMA mixtures.

Among these polymers; Styrene-Butadiene-Styrene (SBS) Styrene-Butadiene-Rubber (SBR), Crumb Rubber Modifier (CRM), Ethyl Vinyl Acetate (EVA), and Styrene Polyvinyl chloride (PVC) [2-6]. Besides the use of polymers as modifiers/additives in asphalt mixtures, currently, an impressive additive such as nanomaterials has been used in most hot mix asphalt projects. According to the literature studies [7-10], adding nanoparticles into asphalt improves their physical, engineering and rheological properties. Studies by [11-17] showed that nanomaterial could fundamentally improve the adhesion and cohesion of asphalt binder/mixture and established bridging impact between the asphalt and nanoparticle, avoiding the growth of cracks.

According to the literature, nano-silica is an excellent additive in pavement modification. There was a new approach of using polymers with nanomaterials as a hybrid polymer to overcome some disadvantages properties of using a single polymer. The application of combining 2% - 4% nano-silica and 5% SBS polymer results in improving the asphalt mixture's performance, in terms of better rutting and fatigue resistance [15-17]. The application of nano-silica with SBS polymer is well investigated as discussed in the literature review, nevertheless, no investigation on the combination of nano-silica and waste HDPE plastic modified C320 bitumen. As such, there is research necessity to investigate and evaluate the engineering, mechanical and deformation performance properties of the combining nano-silica and waste plastic polymer as a "sustainable hybrid additive". The study aims to investigate, evaluate, and find the ideal mixing contents to produce sustainable hybrid additive, which can be effective in both sectors of asphalt modification engineering and polymer recycling industry.

2. Materials and Testing Methodology

2.1 Materials

Australian bitumen C320 is used in this study. The physical properties of C320 bitumen in terms of penetration at 25°C and flashpoint are 44 mm.d and 250°C. local waste plastic milk bottles (HDPE)

are collected, cleaned, ground to a size of 0.41mm, and used as an asphalt additive by 4% content. Nano-silica with a diameter of 15nm, service area of 600m²/g, bulk density <0.056g/cm³, and coated with 2wt% Silan- KH220 is used in this study. Granite aggregate which is the nearly popular natural aggregate in Western Australia was used. Typical, 10 mm, stone mastic asphalt (SMA) for course surfacing was applied.

2.2 Sampling and testing

During the sample fabrication, the Nano silica powder blended with C320 for 1.5 hour at 170 C and 2200 rpm. Before adding the NS modified C302 to the mixture, the aggregate is fully coated and mixed with 4% waste HDPE. Following the Marshall method and the dry-mix process, the waste HDPE and NS-modified-SMA mixtures are sampled at 5.5 optimum binder content. In addition, as advisable by the Main Roads Western Australia (MRWA) standard, 1.2 % hydrated lime by weight of dry aggregate is used. In the testing stage, Marshall test [18], wheel-tracking tests [19], and fatigue are conducted to investigate the engineering properties of the modified asphalt mixture.

3. Results and discussion

3.1 Marshall stability, flow and MQ

Marshall test has been conducted to investigate and assess the ability of SMA mixture to withstand substantial loads of traffic and subsequent failure and rutting deformation. Figures 2,3 and 4 show the results of Marshall stability, Marshall flow, and Marshall quotient. Marshall quotient can be defined as the rutting resistance indicator and can be calculated as the ratio of Marshall stability to Marshall flow [6,20,21]. As can be seen from Figures 2 and 4, the increases in different Nano-silica content along with 4%HDPE has shown an obvious increment in Marshall stability and Marshall quotient, however, Marshall flow shows declined results, as shown in Figure 5. Previous studies [2,12] have indicated that Marshall stability values are an essential indicator of asphalt resistance to shear stress, displacement, and rutting deformation. Adding 6% nano silica and 4% HDPE could establish the ideal stability and strength properties of SMA mixture with high

Marshall stability and Marshall quotient as shown in Figures 2 and 4.

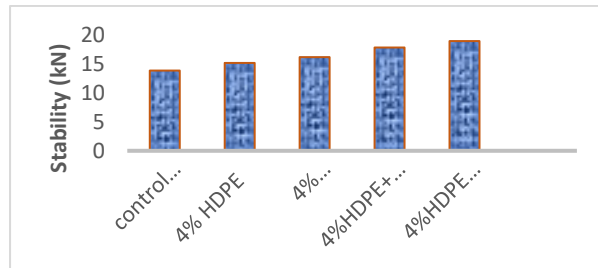


Figure 2: Marshall stability results

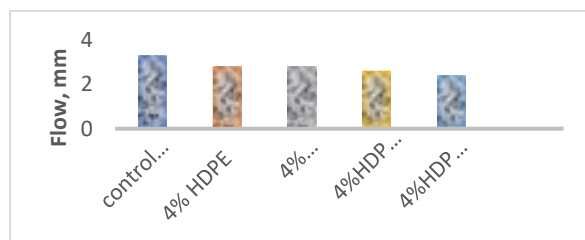


Figure 3: Marshall flow results

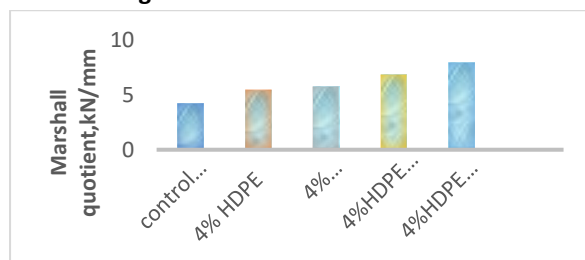


Figure 4: MQ results

The results of Marshall results are in line with the previous studies [21,22]. Nano silica possesses very small fragment sizes and a bigger surface area so that it can absorb more binder and increase the structurally modified binder [23]. The stability and MQ values of all modified SMA samples increased. This signifies that waste plastic and nano silica working significantly to improve the tensile strength and rutting resistance by developing strong connection forces between bitumen binder C320 and aggregate, and, consequently they develop higher resistance to deformation and moisture damage [24].

3.2 Rutting results

Rutting is mainly the most important distress which can result in the deformation of road pavement, specifically in high-temperature climates. Unsuitable mixture design, such as higher bitumen content, a higher percentage of coarse aggregate, and unreasonable filler amount could potentially consequence in rutting deformation. Thus, investigating the effect of the modified

mixtures to explain the rutting resistance is essential.

The rutting test was conducted according to used in main road Australian standard [19]. Figure 5 shows the rutting depth antonymous the different modified mixtures, and the data of the rutting test have used the average of three readings for each mixture type and content. Adding HDPE and Nano silica results in a considerable decrease in rut depth of all modified mixtures in comparison to non-modified mixtures. The results indicate the positive influence of Nano silica and HDPE plastic on rutting resistance. The reason behind these enhancement results is the strengthening adhesion force between bitumen binder C320 and aggregate. Therefore, forbid aggregate from slithering due to the influence of compressive loads, and as such, the rutting deformation decreased [22-24]. This result shows that using more nano-silica in the mixture reduces the rutting depth as compared to non-modified SMA (control binder) and 4% HDPE-modified SMA. However, the result of 4% HDPE is of concern as compared to the non-modified SMA. The results indicate that adding NS and HDPE results in SMA mixture stiffness and strength have been enhanced. This demonstrates a rise in the capability of the modified stone mastic asphalt to withstand and resist accumulative deformation under heavy traffic loads. Therefore, by utilizing HDPE and NS, the rutting resistance of the SMA mixtures are improved.

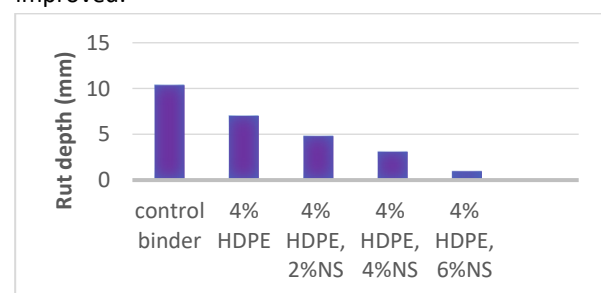


Figure 5: Rutting resistance results

3.3 Fatigue results

The fatigue strength and fatigue life of the PET-Nano-silica-modified asphalt was measured using the four-point bending fatigue test in accordance with Austroads AGPT/233 method. The results show that the increase in nano-silica content with HDPE plastic increased the fatigue to highest level of fatigue life up of hybrid additive of 4% HDPE and

6%NS mixtures. All the modified mixtures were higher than the non-modified mixture which has the lowest fatigue life of only about 65680, as shown in Figure 6. The use of nano-silica with different content of 2%, 4%, and 6% has better fatigue life in comparison to samples of using only 4% HDPE, which can explain that the nano-silica enhanced that the polymer-bitumen phase.

This signifies that nano-silica particles have a substantial consequence on fatigue life of the mixtures. This result could be ascribed by the of nano-silica's surface energy, which to some extents reduces the aggregation of HDPE fragments during the mixing. By this means improving elasticity, stiffness, and connection of binder-aggregates structure [25,26,27].

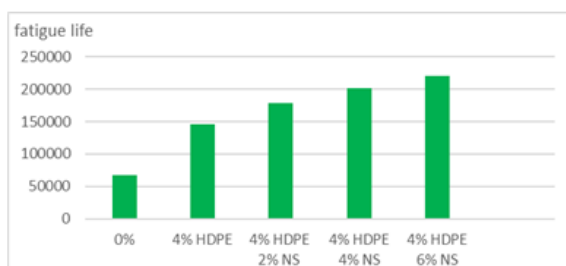


Figure 6: Fatigue results

4. conclusion

In this study, the influence of nano-silica and waste HDPE on the rutting resistance and permanent deformation of asphalt mixtures were investigated and evaluated. By application of wet mix process, NS and waste plastic were blended with C320 binder and SMA mixtures were fabricated. Various contents of NS of 2% to 6% with 4% waste HDPE plastic were used as a hybrid combined polymer/additive. The mechanical and engineering properties were examined and assessed through Marshall stability, Marshall flow, wheel tracking test, indirect tensile strength ratio test, stiffness modulus test, and drain-off tests. To sum up, given tests consequence, the below conclusions can be drawn:

1- The study shows an innovative approach to recycling plastic in asphalt modification and industry. This thesis demonstrates the influence and the possibility of using waste plastic with/without nano-silica as an alternative cost-effective recycled polymer for the modification of bitumen binder C320 and asphalt mixtures

following Australian standards. As 4% HDPE mixtures has the comparative ability to the mixtures with addition of 2%-6% nano-silica, in term of stability and rutting resistance performance.

2- The raises in different Nano silica substances alongside with 4%HDPE has demonstrated an obvious increase in Marshall stability and Marshall quotient, however, Marshall flow shows declined results. The higher Marshall stability values indicate that the hybrid additive of Nano silica-HDPE samples have become stiffer and, as such modified SMA mixtures are more resistant to deformation.

3- Using nano silica results in a sustainable decline in rut depth for mixtures modified with 4% HDPE- 6% NS. The results imply the positive effect of NS and waste plastic on rutting resistance.

4- Using waste plastic and nano silica results in improving the fatigue life and as such enhance the resistance to fatigue cracking and deformation of 4%HDPE and all hybrid samples of waste plastic with nano silica in comparison to control mixture (non-modified mixtures).

5- In addition, it is recommended to do more tests at different stress and temperatures to consider the rutting resistance and fatigue performance. After all, it is recommended to test the fatigue life and fatigue deformation of the different percentages of the hybrid additive using the SMA mixture.

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