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Ethylene Propylene Diene Monomer (EPDM) Effect on Asphalt Performance

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Abstract: The asphalt industry is increasingly developing with greater focus on sustainability. This study focuses on the benefits of a binder modification of stone mastic asphalt (SMA) by adding a rubber—ethylene propylene diene monomer (EPDM)—into a class 320 bitumen. This study observes the advantages that occur for the rutting and fatigue performance of the samples. The binder modification was made by incorporating 0, 2, 4 and 6% binder weight into each sample. The tests performed on the samples were the wheel-tracking test and the four-point beam bending test. The results revealed varied outcomes, with the four-point beam bending test showing the 6% sample having the highest initial stiffness and modulus of elasticity but the lowest cycle to failure. Therefore, the best performer was determined as the 4% sample, which performed consistently throughout, having the highest cumulative dissipated energy and second-highest initial flexural stiffness, modulus of elasticity and cycle to failure results. There was a clear indication of the best performer for the wheel-tracking test, with the 4% sample having the lowest rut depth, although there were signs of further improvement to be achieved within the 4–6% range. In addition, drain-off tests were conducted on the mixtures, and the addition of EPDM significantly reduced the SMA drain-off values. Overall, the best improvements through binder modification for an SMA mix with EPDM concerning fatigue and rutting resistance came from a 4% incorporation.

Keywords: EPDM; fatigue; rutting; asphalt

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1. Introduction

The ever-expanding nature of society has led to an increase in the need for roads. The construction of 122.5 million metric tons of asphalt in 2019 alone increased the annual rate by 2.8% [1]. This increase, although necessary, has taken a toll on the environment since the bitumen used to bind an asphalt mix is a semi-solid form of crude oil, causing greenhouse gas emissions [2]. Bitumen is responsible for 25% of total CO_2 emissions [3]. This highlights the need to find a more sustainable way to produce asphalt as a viable option in the future.

The use of stone mastic asphalt (SMA) is becoming a more viable option, due to its favourable properties, with good durability and extraordinary resistance to fatigue and rutting damage. SMA performs so well, due to its gap-graded nature, giving it a strong skeleton throughout. This strengthening results in a favourable aggregate interaction from its high aggregate incorporation with most SMA mixes, with 70–80% coarse aggregates [4]. However, SMA is not widely adopted because of its higher cost; it is 125% more than that of dense grade asphalt (DGA), the most commonly found asphalt [5].

Binder modification through a recycled polymer has shown promising signs to make SMA a more viable option in the future. This technique, also known as the wet method, has been used since the 1980s and involves adding material to the bitumen (binder) of the asphalt mix to improve the blend's overall properties. Polymers have been commonly used in this process since they improve the rheology of the asphalt, improving the mix's resistance to cracking at a range of temperatures and increasing its ability to resist excessive loadings. Binder modification was not widely adopted because the base SMA properties were previously acceptable, and binder modification was only used for special cases. However, the base properties of SMA may be unacceptable for handling the increased traffic loads in the future [6].

The polymer chosen for binder modification is extremely important since it determines how the bitumen is affected. Ethylene propylene diene monomer (EPDM) is a rubber that can be classified as an elastomeric polymer known to resist high amounts of permeant deformation. EPDM can resist high deformation through its stable structure from crosslinking its diene monomer, making it challenging to break the bond [7]. Other properties to consider when determining the viability of EPDM are its high level of resistance to ultra-violet radiation (UV), capability to resist weather damage, ability to prevent fatigue damage and waterproof nature.

Rutting and fatigue resistance should be improved in an asphalt mix because these two parameters are the main factors that can lower the service life of a road [8]. Therefore, any mitigation of the factors will be beneficial to the industry.

Rutting occurs from excessive repeated traffic loading. It is affected by asphalt's susceptibility to permeant deformation and its strength. Environmental factors that cause rutting result from variations in temperature [9]. Rutting results in lowering a road's trafficability, as it causes the asphalt to deform around a wheel path, making it harder for vehicles to manoeuvre. Therefore, the best way to improve rutting resistance is to increase asphalt's ability to resist permeant deformation, one of the key parameters of EPDM.

Fatigue damage in asphalt, also known as crocodile cracking, occurs when a combination of factors damages the asphalt over an extended period. Excessive load cycles result in cracking within the binder, giving a crocodile skin look. The factors that contribute to fatigue damage are high traffic loading and weather and temperature variations. If fatigue failure occurs, there is no way to stop it [10]. This directly affects the service life of the asphalt. Therefore, prevention is needed rather than slowing the effects. Currently, the primary way to prevent fatigue damage in the industry is using polymer-modified binders. Therefore, adding EPDM is a viable option to give extra options for prevention [11].

From a review of the relevant literature on the research topic, this study is viable. This is due to previous studies showing that polymers, such as HDPE, LDPE and PP, incorporated by 5% into a bitumen mix improved asphalt's rutting and fatigue performance [12]. DGA with 2, 4, 6 and 8% EPDM incorporated into the mix showed improvement in the wheel-tracking test results and four-point beam bending results in all categories [13]. However, there is a gap in the literature concerning the EPDM effect on SMA. Therefore, this study determines how a 2, 4 and 6% EPDM binder weight incorporation affect SMA via wheel-tracking and four-point beam bending testing.

2. Materials

2.1. Bitumen (Binder)

The binder chosen for this experiment was Class 320 bitumen, supplied by SAMI Bitumen Technologies. The binder was chosen due to its more widespread use in high trafficked roads and hot temperatures, the ideal environment for using SMA. The mix consisted of 6–7% of the bitumen to classify it as SMA, according to MRWA Specification 502. The exact percentage of the mix is determined via Marshall testing methods. Table 1 shows the exact specifications of the bitumen.

Table 1. Bitumen Class 320 properties Reprinted from ref. [8].

Property	Value	Unit	Standard
Viscosity at 60 °C	320	Pa·s	AS 2341.2
Viscosity at 135 °C	0.5	Pa·s	AS 2341.2
Pen at 25 °C	Min. 40	DMM	AS 2341.12
Flashpoint	Min. 250	°C	AS 2341.14
Viscosity of residue at 60 °C (% of original)	Min. 300	Pa·s	AS 2341.2

2.2. Fibre

Fibre was chosen according to MRWA Specification 511, which specified that the fibres should be VIATOP premium or TOPCELL cellulose fibres [14]. The chosen fibre was the VIATOP premium fibre to increase a mix's drying time and eliminate the binder's drain off. The amount of fibre was determined as 0.3%, according to MRWA Specification 502. Table 2 shows the specifications of the fibre used.

Table 2. Fibre Properties.

Properties	Value	Unit
Cellulose content	80	%
Mean length	1.10	mm
Mean thickness	0.04	mm
Bulk density	0.47	g/cm^3

2.3. Aggregate

The aggregate for the experiments was supplied by Holcim and taken from local sources around Perth. The aggregate comprised the largest percentage of the mix (nearly 92%), which stayed consistent throughout all the mixes. The three main aggregates used were the graded Holcim stones in sizes 13.2–9.5, 9.5–6.7 and 6.7–4.75, the quarry sand and the baghouse dust. The particle size distribution was made according to MRWA Specification 502 as shown in Table 3. The exact specifications for the aggregate are shown in Table 4.

Table 3. Aggregate grade for SMA10 from MRWA Specification 502 Reprinted from ref. [4].

Australian Standard Sieve Size mm (AS1152)	Percentage Passing (Nominal 10 mm Granite Mix)	
	Lower Limit	Upper Limit
13.2	100	100
9.50	90	100
6.70	25	40
4.75	18	30
2.36	15	28
1.17	13	24
0.600	12	21
0.300	10	18
0.150	9	14
0.075	8	12

Table 4. Aggregate properties.

Property	Value	Relevant Standard
Coarse aggregate (retained by 2.36 mm sieve)		
Apparent particle density	2.6	AS 1141.6.1
Particle density on a dry basis	2.59	AS 1141.6.1
LA value (%)	21.9	AS 1141.23
Water absorption (%)	0.4	AS 1141.6.1
Fine aggregate (retained by 0.075 mm sieve)		
Apparent particle density	2.59	AS 1141.6.1
Particle density on a dry basis	2.58	AS 1141.6.1
LA value (%)	21.9	AS1141.23
Water absorption (%)	0.6	AS 1141.6.1

2.4. Hydrated Lime

The mineral filler was anything that passed 0.075 mm. This project's hydrated lime was chosen, as it is the recommended filler from MRWA Specification 502 and also due to its resistance to moisture level changes. The hydrated lime comprised 1.4% of the mix and stayed consistent throughout the mixes. The specification of the hydrated lime is given in Table 5.

Table 5. Hydrated lime properties Reprinted from ref. [15].

Property	Value	Unit
Solubility (20 °C)	1.65	g/L
(30 °C)	1.53	g/L
Angle of response—Fines	15–80	°
Melting point	2570	°C

2.5. Ethylene Propylene Diene Monomer

The polymer additive chosen for the study was EPDM. It was added in 2, 4 and 6% binder weight percentages. It was supplied by A1 rubber in its virgin form. The EPDM was incorporated into the bitumen via a Silverson mill at 4000 RPM at 180–200 °C. The properties of the EPDM are shown in Table 6.

Table 6. EPDM properties.

Property	Value
Specific gravity	1.5
Tensile strength (MPa)	4.0
Hardness (Shore A)	65 ± 5
Elongation (%)	250

2.6. Particle Size Distribution

The particle size distribution was strictly followed for all mixes to keep it within the range specified by MRWA Specification 502 standards for an SMA mix. The curve for the mix is shown in Figure 1 and shows compliance with the standards.

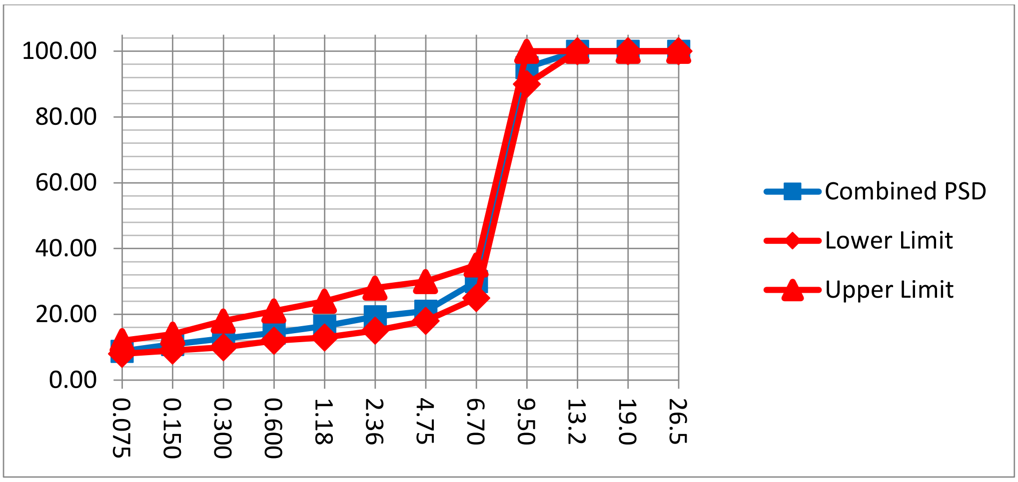

Figure 1. The 0.45 power maximum density curve.

2.7. Final Mix Design

The final mix design chosen for the project is shown in Table 7 and was used for all samples for the wheel-tracking test and four-point beam bending test. The only difference was the percentage of EPDM incorporated into the mix. However, this was to failure as the bitumen percentage since the binder modification method was employed. The percentage was determined via Marshall testing methods, further elaborated in Sections 3 and 4.

Table 7. Final mix design.

Material	Percentage in the Mix (%)
Bitumen	6.42
Fibre	0.30
Holcim 13.2–9.5	4.66
Holcim 9.5–6.7	60.63
Holcim 6.7–4.75	8.40
Quarry sand	10.73
Baghouse dust	7.46
Hydrated lime	1.40

3. Methodology

During the testing phase, the three main experiments were the Marshall testing methods, the wheel-tracking test and the four-point beam bend test.

3.1. Marshall Testing Methods

Marshall testing methods were conducted per ASTM D6927, WA731.1, WA732.2 and WA733.1 to determine whether the mixes were compliant with the parameters set in MRWA Specification 502. Table 8 shows the measurements of the bulk density, maximum density, air voids, Marshall stability and Marshall flow to see if the optimum binder content is compliant in all samples. Figure 2 shows the samples that were made in the laboratory.

Figure 2. Marshall test samples.

Table 8. Marshall test parameters from MRWA specifications 502 Reprinted from ref. [4].

Parameter	Minimum	Maximum
Marshall flow	2.00 mm	5.00 mm
Marshall stability	6.0 kN	-
Voids in mineral aggregate:		
Nominal 10 mm	18.0%	-
Air Voids:		
Nominal 10 mm	3.5%	5.5%

3.2. *Wheel-Tracking Test*

The wheel-tracking test was conducted per AG:PT/T231 and measured the rut depth of the samples shown in Figure 3. It was performed on two identical samples, where the averages were taken. The samples were kept in a mould for testing with a width and length of 300 mm and a thickness of 50 mm. The conditions kept for standardising all tests are given in Table 9.

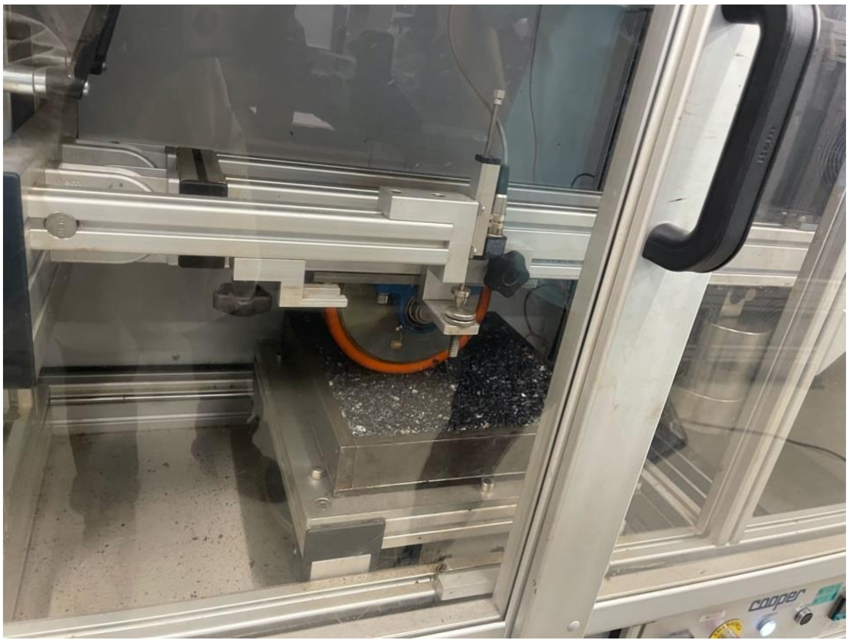

Figure 3. Wheel-tracking test.

Table 9. Wheel tracking test parameters from AG:PT/T231 Reprinted from ref. [16].

Asphalt Wheel-Tracking Test Parameter	Value for Compliance with AG:PT/T231
Test temperature (°C)	60 ± 1
Air void content (%)	5 ± 1
Vertical load (N)	700 ± 20

3.3. *Four-Point Beam Bending Test*

The four-point beam bending test was conducted per AG:PT/T233 and measured the flexural stiffness of the beam samples shown in Figure 4. The test was performed on three identical beam samples, which were cut from a larger slab. Each beam had dimensions of 390 mm × 50 mm × 63.6 mm. The average of the three samples was calculated to obtain a final result. The conditions kept for standardising all tests are given in Table 10.

Figure 4. Four-point beam bending test.

Table 10. Four-point beam bending test parameters from AG:PT/T233 Reprinted from ref. [17].

Four-Point Beam Bending Test Parameter	Value for Compliance with AG:PT/T233
Test temperature (°C)	20 ± 0.5
Loading frequency (Hz)	10 ± 0.1
Peak tensile strain for the 50th and subsequent cycles ($\mu\varepsilon$)	400 ± 10 (i.e., ±2.5%)
Air void content (%)	5 ± 0.5
Number of replicants	3

3.4. Drain-Off Test

The drain-off characteristics of SMA mixtures can be studied with two methods. The two tests are the Schellenberg test and the Basket drainage test. In Australia, the Schellenberg test is more popular. In SMA mixes, there is a possibility for the binder to be drained. Therefore, as per AG:PT/T2351 [18] the test considered 1 kg of loose asphalt mixes and kept them in the oven for a time of 1 h ± 1 min. The temperature was set as 175 °C ± 3 °C tolerance [8]. Finally, the drain-off values were recorded. The results are further presented in the next section.

4. Results and Discussion

There were three tests performed throughout the testing period: the Marshall testing methods, the wheel-tracking test and the four-point beam bending test. Each followed their standard, as shown in Section 3. Each test was performed on samples that contained 0 (control), 2, 4 and 6% EPDM.

4.1. Marshall Testing Methods

The results of the Marshall testing methods performed is shown in Table 11. Compliance with the parameters set up in MRWA specification 502 is shown in Table 8. The bulk density and maximum density from the testing showed similar results, indicating that all the results were higher than the control result. This reveals that bitumen became denser, due to EPDM having a higher density of 900 kg/m^3, than the bitumen with 1.04 kg/m^3. However, it did not affect the bitumen's density drastically, due to the incorporation percentage being low.

Table 11. Marshall testing methods results.

Parameter	Results			
	Control	**2%**	**4%**	**6%**
Maximum density (t/m^3)	2.413	2.420	2.426	2.422
Bulk density (t/m^3)	2.283	2.288	2.294	2.295
Air voids (%)	5.397	5.450	5.438	5.252
Marshall stability (kN)	7.380	8.801	9.169	8.054
Marshall flow (mm)	2.446	2.417	3.005	2.328

The air voids in the mix showed that the mixes were all compliant with MRWA Specification 502 and the specifications set up in the experiment. There was no clear trend to the air voids since the 2 and 4% EPDM incorporations had high air voids, compared to the control. Meanwhile, the 6 % EPDM was low, compared to the control, due to the incorporation process, which had trouble fully incorporating the EPDM into the bitumen, as shown in Figure 5.

Figure 5. EPDM residue in bitumen.

The Marshall stability results revealed that all the EPDM samples performed better than the control in the performance testing. The Marshall flow results were all within the range given in Table 8 and showed consistency throughout all samples. The Marshall stability and flow tests both showed that the 4 % EPDM performed the best, having the highest values, indicating how performance testing will happen.

4.2. Wheel-Tracking Test

The results for the wheel-tracking test are given in Figure 6 and show the rut depth over time. They give a final result at 10,000 cycles, with a lower rut depth indicating better performance. All the EPDM samples performed better than the control sample, with the best 4% result performing 342% better than the other percentages. The results show how the EPDM made the binder more resistant to permeant deformation. The graphs for the control are more linear, whereas the EPDM samples reach a point before slowing. This is because one of the key features of an elastomeric polymer is resistance to permeant deformation, which is transferred to the bitumen (binder) of the mix. The results of the wheel-tracking test reflect the results found in the Marshall stability and flow, which show that 4% EPDM is the percentage with the best deformation properties.

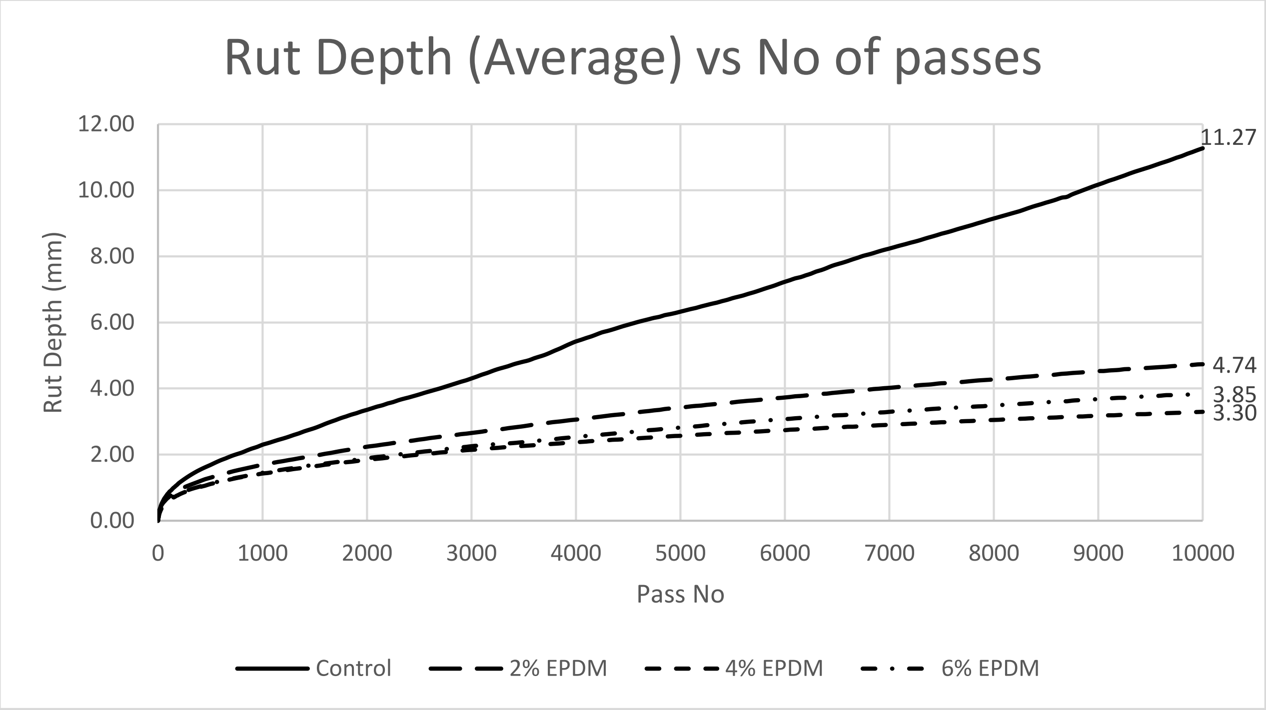

Figure 6. Wheel-tracking test results.

4.3. Four-Point Beam Bending

The initial flexural stiffness and modulus of the elasticity showed how much fatigue the sample could handle. Results are shown in Figures 7 and 8, with higher results indicating better performance. From the results, the 6% EPDM sample is shown to have the highest values in both categories of initial flexural stiffness (IFS) and modulus of elasticity than the control.

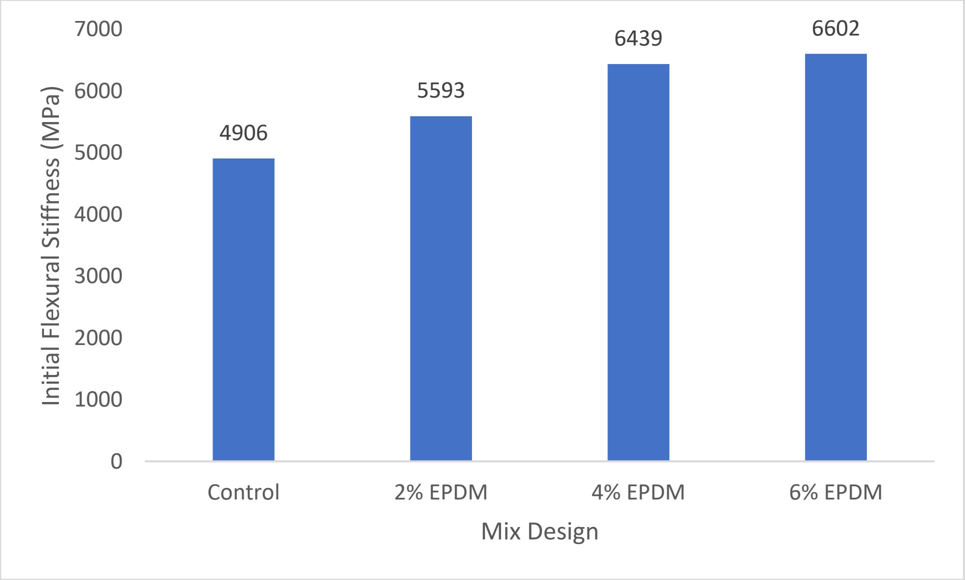

Figure 7. Initial flexural stiffness results.

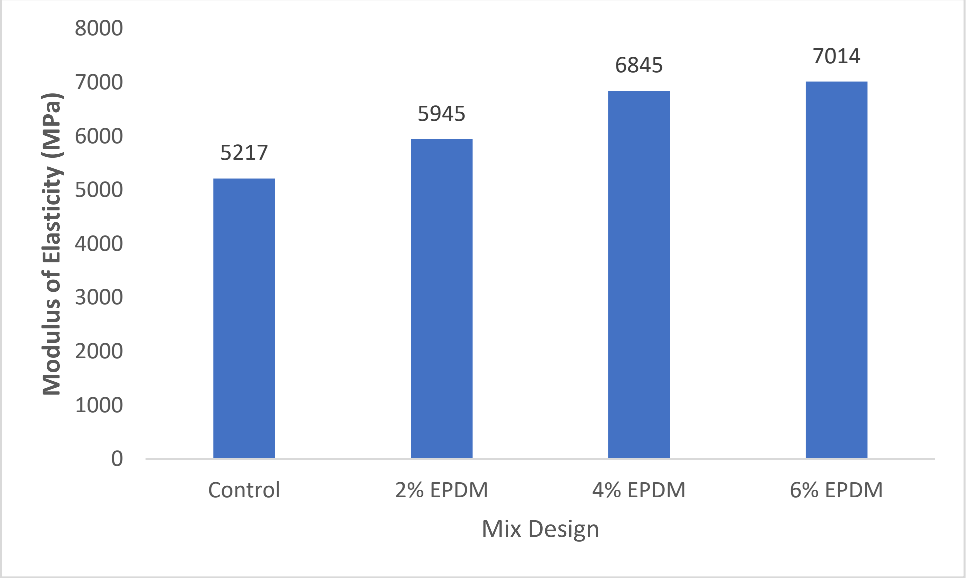

Figure 8. Modulus of elasticity results.

The cycle to failure and cumulative dissipated energy show the service life capability of the samples shown in Figures 9 and 10, with a higher score indicating a sample resisting more fatigue in the long term. All the samples in the cumulative dissipated energy performed better than the control. Therefore, EPDM could have a longer service life. However, in the cycle to failure, the 6% EPDM samples indicate that incorporating 6% may adversely affect the service life of the asphalt. Therefore, an ideal amount would lie between 2 and 4%.

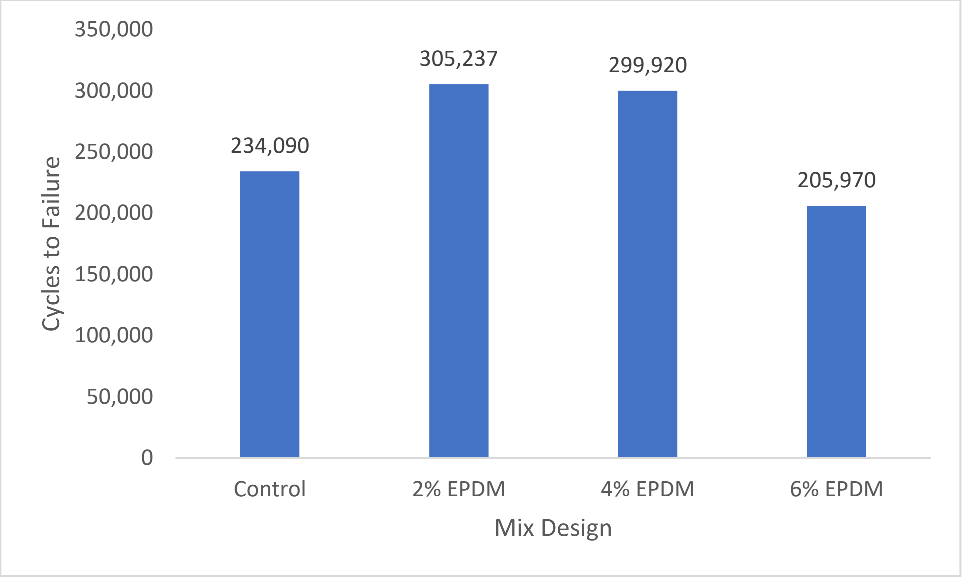

Figure 9. Cycle to failure results.

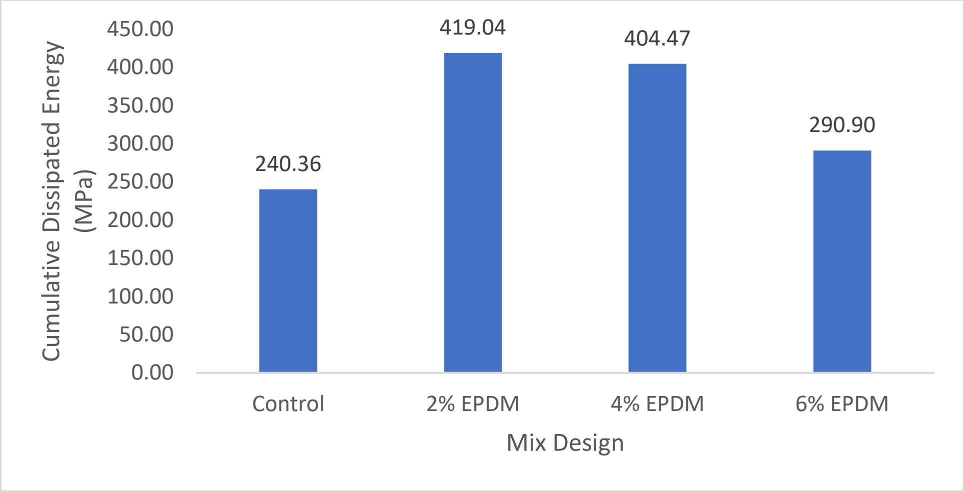

Figure 10. Cumulative dissipated energy results.

From all the four-point beam bending results, the best performer was the 4% EPDM sample because the 2% and 6% results were inconsistent throughout all categories. The 4% sample consistently had the second-best or best results throughout the test. Therefore, it is the ideal incorporation amount for the samples.

4.4. Drain-Off Test

In order to investigate the drain-off capacity, the Schellenberg drain-off test technique was implemented on the mixes in accordance with Austroads AG:PT/T235 [18].

The results can be seen in Figure 11. As can be seen, the addition of EPDM decreased the drain-off rate. A drain-off value of below/equal to 2% is viewed as great. The advantage of adding EPDM was the creation of good grip and bonding in the bitumen and, consequently, a decreased drain-off rate.

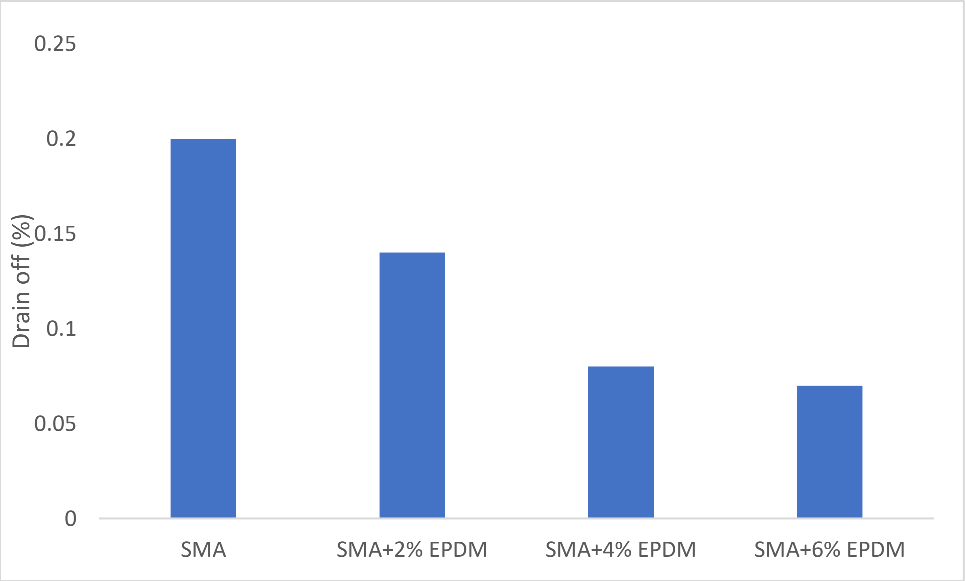

Figure 11. Drain-off test results.

5. Conclusions

This study measured the effect of EPDM on SMA concerning rutting and fatigue resistance, using binder modifications. SMA mixes were prepared, using a Silverson mill to incorporate EPDM into the Class 320 binder. The incorporation amounts of EPDM were 0% (control), 2%, 4% and 6%. The Marshall testing method, wheel-tracking test, and four-point beam bending test measured the performance of each sample. Each test was performed under specific test conditions to ensure that an accurate measurement was found. The following conclusions can be drawn from the results:

- For Marshall stability and flow tests, the 4% EPDM sample incorporation had the best results, having the highest results in each, with a stability of 9.169 kN and a flow of 3.005 mm. However, all EPDM samples improved over the control sample in the Marshall stability test, and all samples fell within the Marshall stability range.
- In relation to rutting resistance, the 4% sample with a final rut depth of 3.30 mm was the best performer, which improved on the control sample by 342%. Overall, adding small amount of EPDM was found to be useful in reducing the rutting value.
- The four-point beam bending test showed that 4% EPDM had the best fatigue resistance. The 4% EPDM had the best fatigue service life, having the best results in the cycle to failure with a value of 324,715 cycles. The 4% EPDM sample had the second-best performance in IFS with a value of 6439 MPa. The 4% EPDM also performed the second best in the cumulative dissipated energy with a value of 404.47 MPa. This meant that the 4% EPDM would have the best performance overall for fatigue resistance.
- In the drain-off test, the 4% and 6% EPDM recorded very close values; they were the best performing in this test and obviously met the standard limit.

6. Recommendations

Some recommendation for further studies can be listed as follows:

- Digestion of EPDM in its granular form into bitumen can be a matter of further investigation.
- For the fatigue life of asphalt, the temperature matters greatly in how the samples are affected; therefore, more testing using different temperatures, such as 10 °C and 30 °C, should be utilised to see if the results stay consistent.
- Different types of EPDM should be utilised in all testing to see if the results are consistent to ensure that the sustainability aspect of the study topic can be ensured.

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