

INVESTIGATING THE DYNAMIC CREEP OF POLYMER MODIFIED HOT MIX ASPHALT

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Abstract

Jordan's road network continues to deteriorate as a consequence of the continuous increase in traffic and the absence of adequate maintenance work. The primary objective of this study was to enhance HMA performance by using polymer-modified asphalt mixtures. The polymer modifier known commercially as Eastman (EE-2) was mixed with binder penetration grade (60–70) at a ratio of 12%. In order to investigate the performance of polymer, the dynamic creep, the resilient modulus and the stability-flow tests were performed. Marshall Mix design was utilized to prepare a total of 50 samples, of which 20 were used to determine the optimal binder content, and the remaining samples were used to determine the effect of EE-2 modifier on asphalt mixtures. The results showed that the optimal asphalt content was 4.57 percent and revealed that the addition of EE-2 polymer to asphalt cement contributed to the production of a variety of desirable properties. The most important indicator of these developments is increased rutting resistance. For instance, the total permanent deformation has decreased by 87% (8500 to 1000 μm). Conversely, addition of EE-2 has resulted in a threefold increase in the resilience modulus (from 3632 to 10590 MPa). Finally, effect of the EE-2 polymer on the stability was demonstrated by increasing the stability value by about 52%.

Keywords:

Asphalt Mixture;
Polymer;
Dynamic Creep;
Resilient Modulus;
Rutting.

1 Introduction

Bituminous mixtures are used as wearing and Binder layers in a pavement structure to distribute stresses caused by loading and protect underlying unbound layers from the effects of water. To adequately perform both of these functions over the pavement's design life, the mixture must also withstand the effects of air and water, resist permanent deformation, and resist cracking caused by loading and the environment. In flexible pavement analysis, a load on the surface of the pavement causes two strains, which are considered the main critical factors for design purposes. These are the horizontal tensile strain (ϵ_t) at the bottom of the bituminous layer and the vertical compressive strain (ϵ_c) at the top of the subgrade layer. These strains depend on the properties of the materials used in the different layers of a flexible pavement. The performance of bituminous mixtures can be defined by their ability to resist permanent deformation, fatigue cracking, moisture-induced damage, thermal cracking, and the mixture's overall stiffness. Aggregate gradation can affect these and other properties such as skid resistance, field constructability, and the asphalt binder's aging characteristics. Asphalt pavement strengthening can be achieved by various techniques, including the modification of asphalt binders. Various types of modifiers have been tested by researchers to mitigate the distress associated with the behavior of conventional asphalt binders [1-4]. Many researchers concluded that the asphalt binder modification increased the complex modulus of bitumen at high temperatures while reducing it at low temperatures [5-9]. Also, the bitumen modifier shows high resistance to thermal cracking, rutting, and

stripping [10]. On the other hand, the modified asphalt with SBS increased the rutting potential after short-term aging from 48 % to 91% by using different percents of SBS polymer [11]. Several studies compared different types of polymers. For instance, the difference between two polymers, SBS and EE2, was investigated by [12]. The study concluded that the polymer-modified mixes showed an improvement in strength and less susceptibility to moisture. In addition, the plastomer-modified binder (EE2) had a lower viscosity compared with the elastomer-modified binder (SBS). In general, the rutting resistance of the polymer modified binders (PMBs) was better compared to the unmodified binders. The modification process with SBS and EE2 increased the fatigue cracking $G^*/\sin \delta$ of the binders. The importance of adding EE2 polymer was eliminated by proving its improvement to the basic specifications of asphalt, like decreasing penetration, increasing softening point [13]. Moreover, both of stability and mixture density were found to be increased by adding EE2 to the mixture compared to the unmodified mixture and other polymers. The Marshall stability and Marshall quotient values showed improvement for mixtures modified with Crumb Rubber CR, EE2, and Diphenylamine (DPA) polymers up to 12% and then a drastic reduction. Hence, the mixtures modified with 12% EE2 showed maximum stability and Marshall quotient values and, hence, improved resistance against deformation [14]. Moreover, the effect of the combination of nanoclay (NC) particles and high-density polyethylene (HDPE) on the modified AC mixture was investigated by [15]. The results showed that employing NC/HDPE significantly increased the penetration index and thereby enhanced binder temperature sensitivity. Evaluation of the effect of polymer additives on rutting resistances via conducting dynamic creep tests was studied by [4, 16]. The loading with 0.5 HZ repetition (with 500-millisecond loading and 1500 ms rest) was selected according to the Australian code (AS 2891.12.1, 2015), and the rutting resistance of asphalt mixtures is evaluated regarding the cumulative strain curve [4]. However, 1000 ms (a pulse compressive load of 100 ms with a rest period of 900 ms) was applied in [16]. The resilient modulus (MR) was used to evaluate the relative quality of materials and the performance change in HMA mixtures with polymer additives [4, 17, 18]. These studies showed that the MR value is highly affected by the temperature and moderately by the load duration, whereas the mix parameters have a lower influence on the MR. Researcher replaced the basaltic crushed stone dust with the optimum value of 13 % of Saw Dust Ash (SDA) as filler material in asphalt. The results indicated that the addition of SDA could decrease permanent deformation and stripping in the mixes because the high concentration of calcium carbonate in the ash reduces rutting and moisture damage potentials [19]. This article aims to check the effect of adding EE2 polymer on the hot mix asphalt properties of wearing courses for heavy traffic. The testing includes tests like dynamic creep, Resilient Modulus and Stability.

2 Methodology

The main objective of this research is to analyze and contrast the characteristics of modified and unmodified hot-mix asphalt. In this study, the utilized modifier is the Eastman (EE-2) polymer. This polymer is a medium-density polyethylene polymer that is combined with asphalt binders to enhance its durability. The experiment involved one type of aggregate (granite), one type of asphalt (60/70) penetration grades, and one type of aggregate gradation (surface layer). Various tests such as Marshall stability, Resilient Modulus, and the Dynamic Testing System DTS-16 at 60 C° creep tests were conducted to evaluate the performance of both modified and unmodified mixes.

3 Materials

3.1 Aggregates properties

The aggregate used in this study was obtained from the existing crushers in the southern region of Jordan. The four aggregate component materials were proportioned to satisfy the grading limits of the required specifications. The used aggregate and their tests' results are presented in Table 1. The characteristics of the aggregate used is presented in Appendix 1.

Table 1: Composition of the aggregate.

Aggregate samples	Description
Coarse Aggregate (Folleyeh)	Crushed granite Materials
Coarse Aggregate (Homseyeh)	Crushed granite Materials
Medium aggregate (Adaseyeh)	Crushed granite Materials
Fine Aggregate	Crushed 25% Limestone, 75% granite

3.2 Hot Mix Formula

3.2.1 Materials and aggregate proportioning in job mix formula

Table 3 shows the aggregates and asphalt cement binder components that were tested and then added to the asphalt mix. The four materials that make up hot bin aggregate were mixed in the right amounts to meet the grading limits of the required specifications. Several attempts were made, and Table 3 shows the proportions that worked best. Using the percentages shown below, the combined aggregate grading shown below was found. Fig. 1 shows the specs, the grading limits, and the job mix formula for grading. Note that the recommended amounts of aggregate are based on the samples that were brought to our labs.

Table 2: Materials and aggregate proportioning in job mix formula.

Aggregate samples	Description	Recommended Proportions by Weight
Coarse Aggregate (Folleyeh)	Crushed granite Materials	5.0%
Coarse Aggregate (Homseyeh)	Crushed granite Materials	14.0%
Medium aggregate (Adaseyeh)	Crushed granite Materials	36.0%
Fine Aggregate	Crushed 25% Limestone, 75% granite	45.0%
Total		100 %
Binder	Bitumen grade 60/70 from the Jordanian Petroleum Refinery.	
Polymer	Polyethylene polymer EE2 (Westlake). The modified bitumen was prepared from the above components using 12.0 % EE2 polymer by total of bitumen [20].	

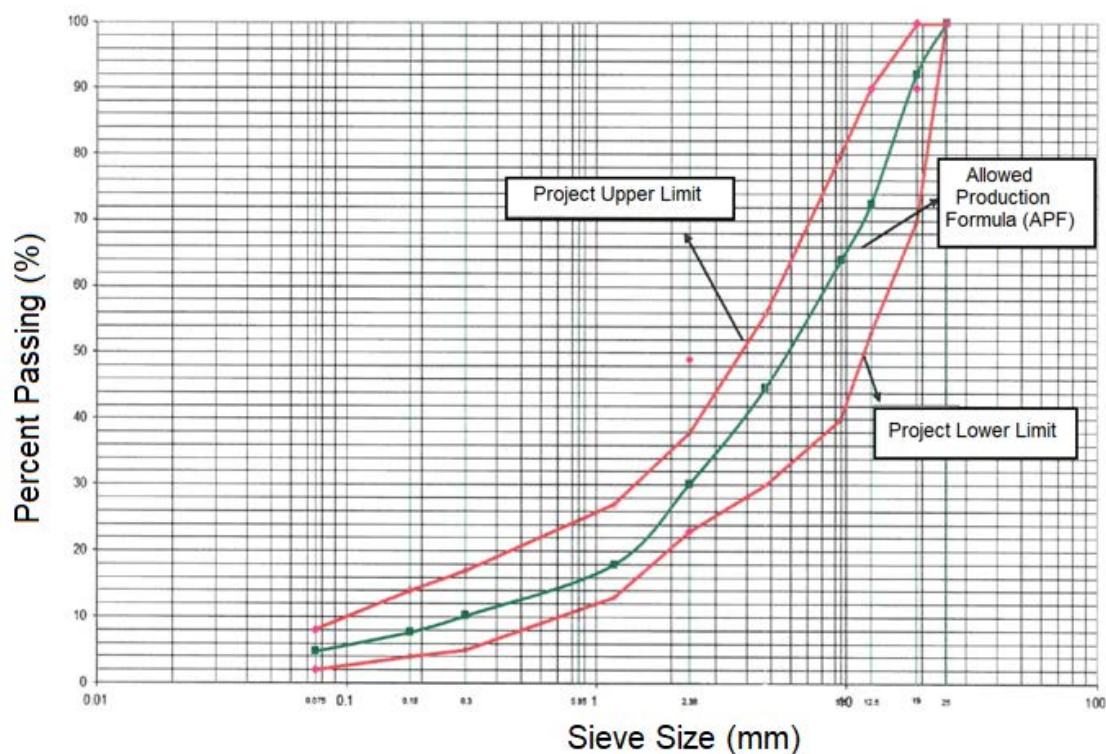


Fig. 1: The specifications grading limits and Job Mix Formula grading.

3.2.2 Trial mix

All the steps for the hot mix process, including mixing and testing, were carried out according to the MS-2 procedure. Six trial mixes were made, incorporating the recommended combined grading and increasing percentages of binder content from 3.5% to 6.0% by weight of the total mix. The Marshall Method was used for the preparation and testing of the specimens, i.e., in accordance with ASTM D 6926, "Preparation of Asphalt Mixture Specimens Using Marshall Apparatus". This method assists in the determination of the "stability" and "flow" of a mix as well as providing a standard method for preparing samples. The Marshall Hammer was used to apply 75 blows to each face of each specimen.

All results are shown in Table 4. The obtained values of the unit weight, stability, flow, stiffness, air voids, and void in mineral aggregate (VMA) are plotted against the binder content in Fig. 2. From these curves, the binder content of 4.57% by weight of the total mix was used for preparing dynamic creep and resilient modulus (MR) samples.

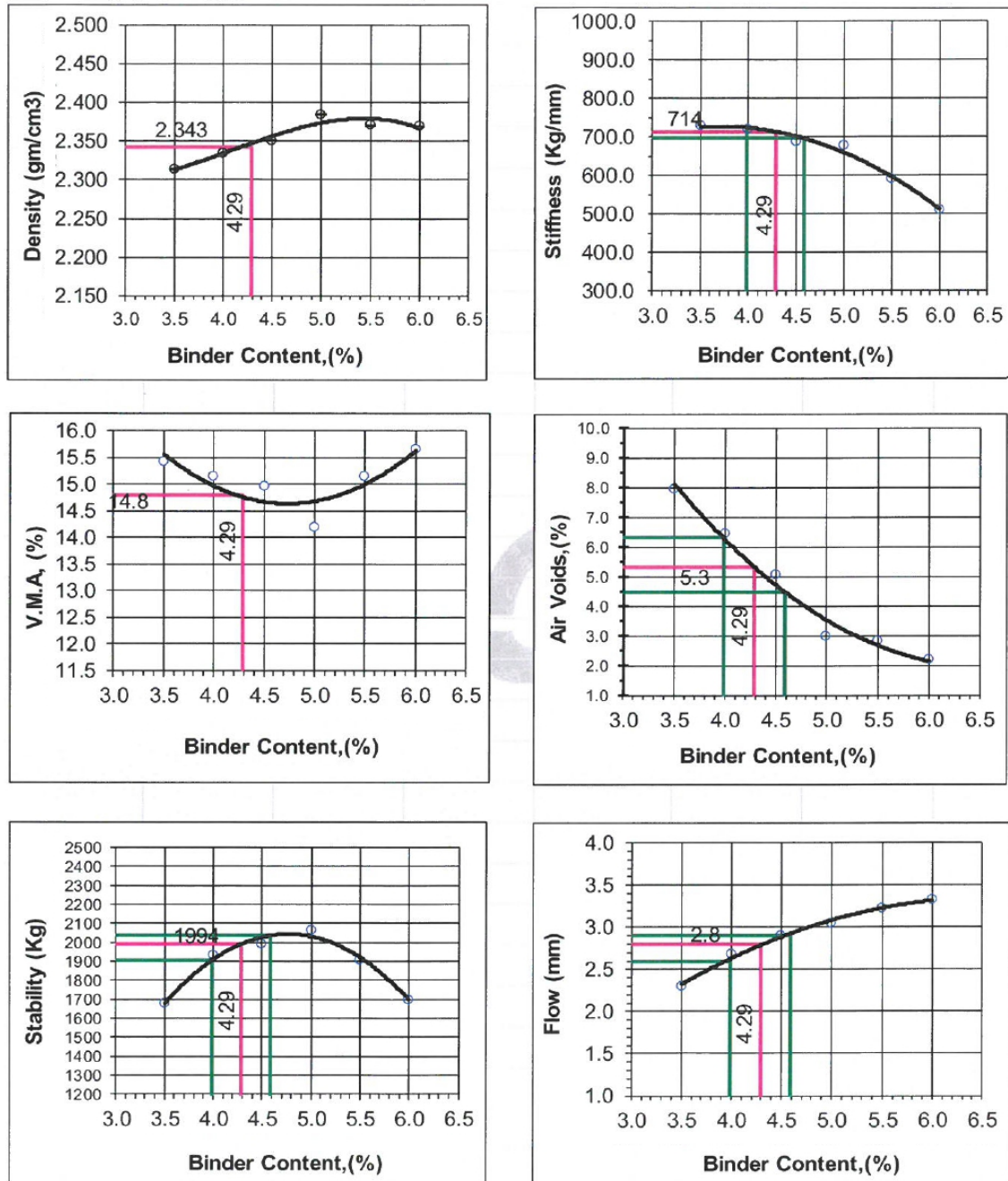


Fig. 2: Bitumen Content VS Asphalt mixture properties.

4 Results and Discussion

4.1 Creep Dynamic Test

Applying the confined or unconfined creep test generally allows for the estimation of asphalt mixtures' rutting resistance. However, the confined test is considered to be more realistic as it can apply both vertical and horizontal stresses under the same conditions that existed in the place. The specimens were tested in a dynamic creep test using the DTS-16 at 60 °C. The potential for rutting was investigated in terms of the total accumulated micro strain as follows: The main principle of this test is to apply load to the mixtures and then measure the resulting deformation. The results of this test are then typically

plotted in terms of the cumulative permanent strain versus the number of loading cycles. In the end, the resulting graph is divided into three major zones: the primary zone, the secondary zone, and the tertiary zone. Fig. 3 illustrates this behaviour; it shows that by increasing load repetitions, the amount of permanent deformation accumulates rapidly for the first several hundred loading cycles in the primary zone. Then, in the secondary region, the unrecoverable deformation rate per cycle decreases and becomes quite steady. Finally, accelerated deformation begins to appear, leading to failure in the tertiary zone [21].

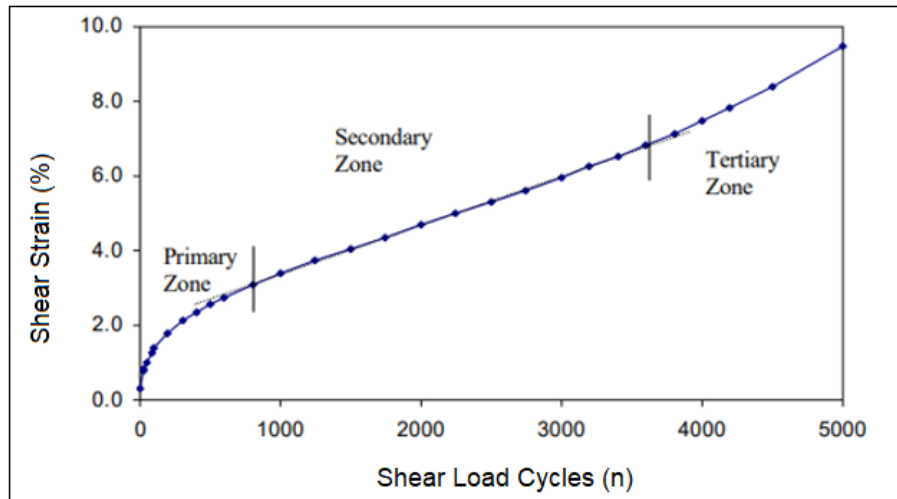


Fig. 3: Typical repeated shear at constant height test data (Brown et al., 2001).

4.2 The Accumulated Micro-Strain

Generally, the accumulated strains can be considered a good indicator of rutting resistance for asphalt mixtures since they account for changes in the amount of permanent strain from cycle to cycle; however, lower accumulated strains indicate more resistance to rutting. A total of eight samples were used in this test, four as reference samples (not modified) and the other four as modified (12% EE-2). Testing of the samples showed that the first one of the reference samples had been damaged completely before reaching 1500 cycles, as shown in Fig. 4. Also, the second unmodified sample showed that the sample reached the tertiary zone (failure zone) before completing the 10000 cycles, as shown in Fig. 5. In contrast, the other unmodified samples (3+4) completed the 10,000 cycles before reaching the failure zone. The average results of unmodified samples are presented in Fig. 6. Fig. 7a shows the setting of the sample for Resilient modulus testing while Fig. 7b represents the sample under dynamic creep test after reaching failure threshold.

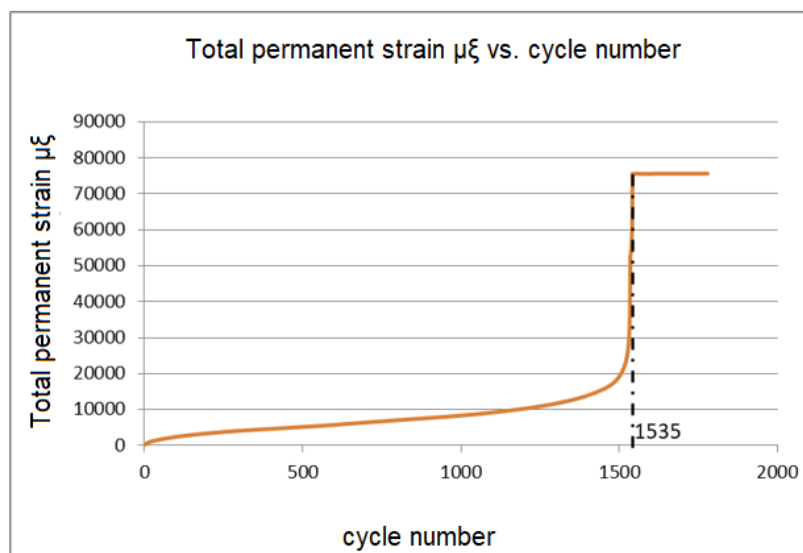


Fig. 4: Unmodified samples#1 damage.

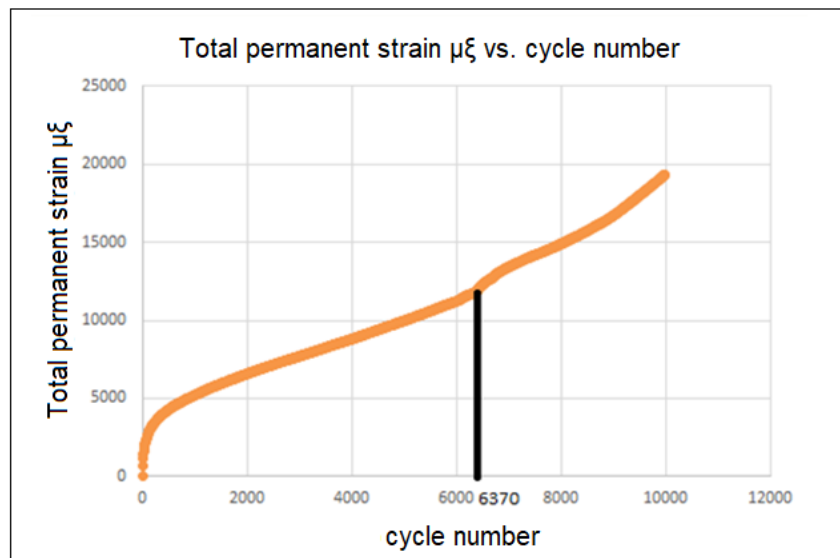


Fig. 5: Unmodified samples#2 damage.

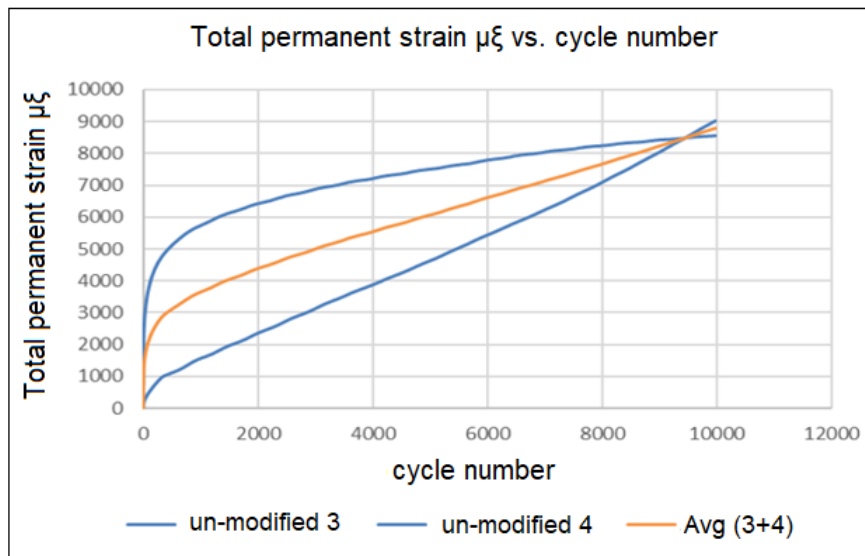


Fig. 6: Unmodified samples (3+4) damage.



a)

b)

Fig. 7: a) Resilient modulus test, b) Sample under dynamic creep test.

On the other hand, the results of the EE-2 polymer-modified samples showed a clear improvement in rutting resistance. Fig. 8 showed that the accumulated strain rate in the three modified samples was about 1000 $\mu\epsilon$ as shown in. The average accumulated strain for modified and unmodified samples is shown in Fig. 9. Comparing the performance of modified samples to the reference ones, it is obvious that the addition of EE-2 polymer resulted in reducing the accumulated strain to approximately 11.8 percent (8700 to 1000) $\mu\epsilon$ of its value for unmodified samples. In other words, the rutting resistance has improved. The reason for that is conventional asphalt mixtures are unable to withstand the rise in axle loads and tire pressures [22]. In contrast, adding EE-2 polymer means the binders become stiffer (higher rutting resistance). Many factors impact the behavior and efficiency of polymers, including bonding types, structure, and chemistry [23].

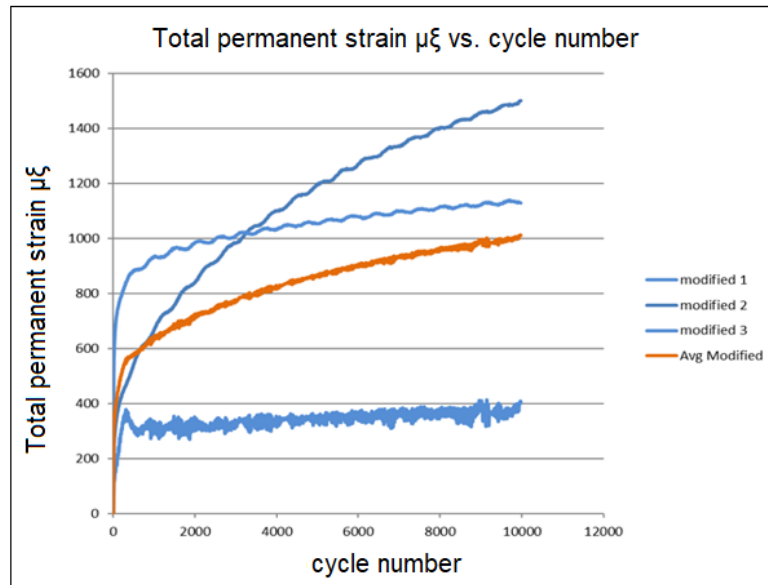


Fig. 8: Modified samples damage.

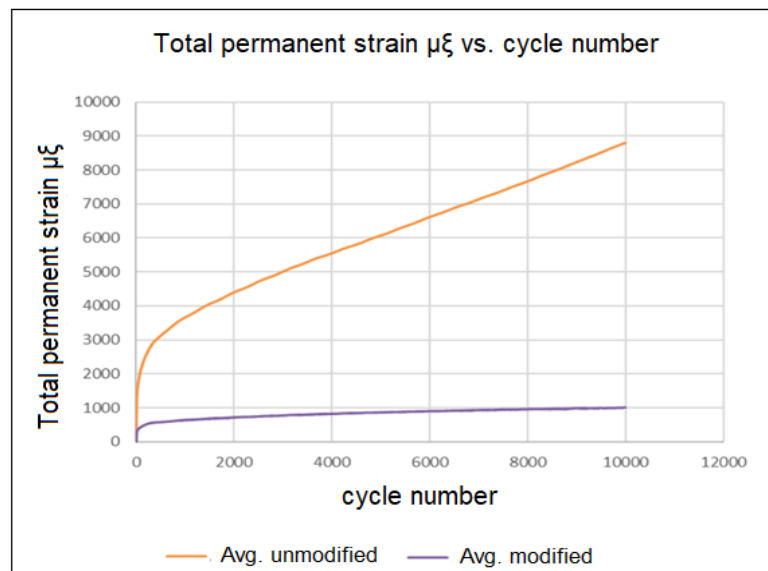


Fig. 9: Modified vs. Unmodified creep test.

4.3 Resilient Modulus (MR)

Resilient Modulus can be defined as the ratio of the applied stress to the recoverable strain at a certain load and temperature. This value is used to determine the effectiveness of adding EE-2 polymer on the stiffness of the hot asphalt mixtures. Three samples of modified and three of unmodified samples were used in this test. The results of this test which was applied at 25 °C are shown in Fig. 10.

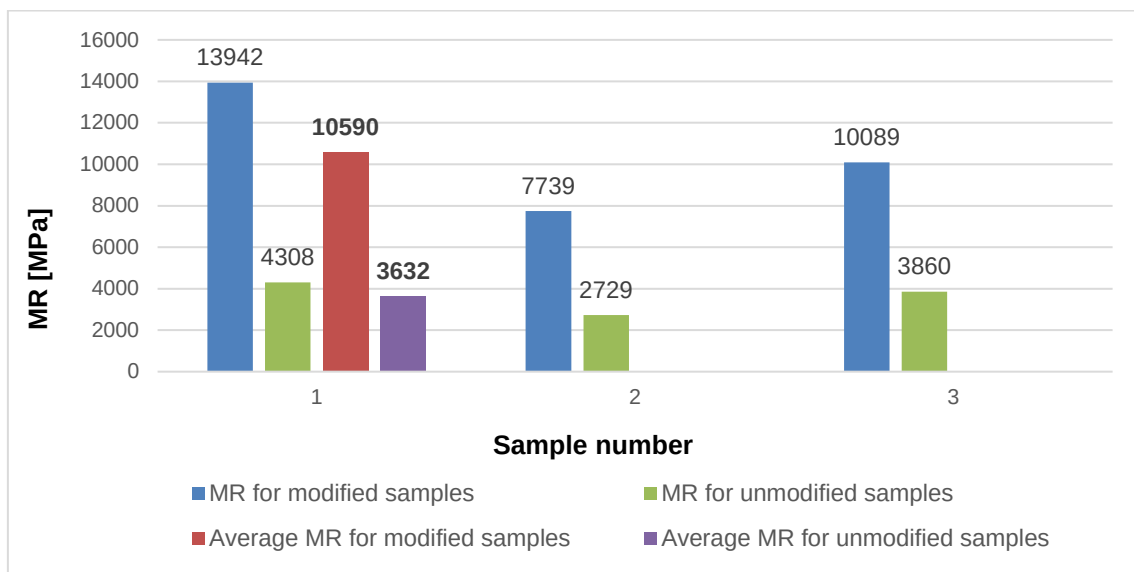


Fig. 10: Modified vs. Unmodified resilient modulus.

Based on Fig. 10, testing the modified and unmodified samples showed that the modified three samples have resilient modulus 13942, 7739, and 10089 respectively with an average of 10590 MPa. While the unmodified three samples have 4308, 2729, and 3860 with an average of 3632 MPa. On other word, the average resilient modulus for modified samples with EE2 polymer (10590) is 3 times stronger when compared to unmodified samples (3632) MPa.

4.4 Stability-flow test

The Marshal Stability-Flow Test was performed on modified and unmodified samples. The testing of six modified samples showed that the average stability was 2424 kg compared to 1605 kg for reference samples, as shown in Table 4. In other words, the EE-2 polymer at 12 percent increased the stability by approximately 52%. This conclusion agrees well with those of Mohammad T. Awwad et al. [19]. On the other hand, the minimum and maximum flow of 2.37 and 3.53 mm were reported, respectively, for asphalt mixtures modified with EE2, regardless of the proportion of bitumen content. On average, the modified mixture with 12% EE-2 modifier represents 3.02 mm of flow compared to 2.86 mm for the reference mixture (around a 5% increase in flow).

Table 3: Stability-Flow results.

#	Marshal stability [kg]		Flow [mm]	
	Modified	Unmodified	Modified	Un-Modified
1	2360	1461	2.37	2.4
2	2430	1510	2.76	2.8
3	2560	1650	2.95	3.1
4	2384	1702	3.17	2.95
5	2418	1675	3.34	3.05
6	2392	1632	3.53	2.85
Average	2424	1605	3.02	2.86

5 Conclusion

The objective of the present study was to demonstrate the effect of (EE-2) polymers on hot asphalt mixes. In the experimental work, the asphalt penetration grade (60–70) was utilized. The characteristics of the asphalt binders were determined using the dynamic creep test, resilient modulus, and stability-flow tests. The results showed that the polymer-modified mixes showed an improvement in stability and less susceptibility to flow. For example, the modified mixture showed around a 50% increase in stability compared to the unmodified (1605 to 2424 kg). In contrast, the flow represented a slight decrease (3.02 for modified to 2.86 mm for reference). Furthermore, the EE-2 asphalt modifier had a high effect on

fatigue life. For instance, the total cumulative permanent deformation of the modified mixture was recorded at 1000- μm . While for an unmodified mixture, the value has reached 8500- μm . In other words, the permanent deformation of the modified mixture was 1/8.5 of the reference. Finally, the unmodified mixture showed one-third of the modified mixture's resilient modulus.

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Appendices

Appendix1: Aggregate sieving and technical properties.

	Standard Test method	Course aggregate Granite (Folleyeh)	Course aggregate Granite (Homseye)	Medium aggregate Granite (Adaseyeh)	Fine aggregate Granite	Fine aggregate limestone
- Sieve Analysis:	ASTM C 136-2014	% PASSING BY WEIGHT				
Sieve Size, mm						
1" (25.0 mm)		100	100	100	100	100
3/4" (19.0 mm)		95	100	100	100	100
1/2" (12.5 mm)		1.0	7.5	100	100	100
3/8" (9.5 mm)		0.3	1.1	72	100	100
No.4 (4.75 mm)		0.2	0.5	3.1	97	100
No.8 (2.36 mm)		0.2	0.5	2.6	79	87
Fine Aggregate		0.2	0.5	1.6	63	75
No.16 (1.18 mm)		0.2	0.4	1.2	27	56
No.50 (0.300 mm)		0.2	0.4	1.1	17	43
No. 80 (0.180 mm)		0.2	0.3	1.0	28.7	19.8
No.200 (0.075 mm)	ASTM C 117-2017					
- Specific Gravity (SG)	ASTM C 127-2015	2.71	2.69	2.68	2.58	2.51
- Bulk SG. (Oven Dry)		2.74	2.72	2.71	2.63	2.59
- Bulk SG. (SSD)		2.79	2.78	2.77	2.70	2.74
- Apparent SG.		1.0	1.2	1.2	1.6	3.3
- Water Absorption (%)	ASTM C 128-2015	12.1	11.5	14.7	-	-
Elongation Index (%)		13.4	10.2	11.9		-
Flakiness Index (%)		5	10	14	21	20
-Soundness, % Loss	ASTM C88-2013	22	26	28		-
-L.A. Abrasion (500 rev.), %		23	22	22	-	-
-Abrasion Loss 100/500 Revs.		100	100	100	100	10
-Fractured Faces (%)	ASTM D5821-13	100	100	100	100	100