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Effect of Recycled Low-Density Polyethylene and Waste Paper Fiber on Stone Matrix Asphalt

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Abstract

The current study investigates the effects of recycled low-density polyethylene (R-LDPE) polymer and waste-paper fiber (w-PF) on the performance of the binder and stone matrix asphalt (SMA) mixtures. The effect of R-LDPE and W-PF was investigated individually and collectively on both the volumetric (bulk density, air voids, voids in mineral aggregate, and voids filled with asphalt) and mechanical properties (Marshall stability, flow and Marshall modulus). W-PF fibers were added to SMA mixtures in different ratios of 0.3 %, 0.5 %, and 0.7 %, while 3% of R-LDPE was added to improve asphalt mixture performance. The results showed that incorporating both R-LDPE and w-PF in asphalt binder has a positive effect on mixture performance, but with various levels. Collective modifiers have increased air voids, voids in mineral aggregate, Marshall stability and marshal modulus up to 15 %, 3%, 42% and 70%, respectively, at 3.3% MC (mix collective additives) in comparison to control SMA. The results also show a reduction in bulk density, voids filled with asphalt and flow to the level of 0.6%, 4% and 49%, respectively. This indicates that the use of waste and recycled materials, especially in the combined form offers a sustainable approach to stabilizing asphalt binder for SMA mixtures.

Keywords: Marshall stability; modified asphalt binder; recycled low-density polyethylene; stone matrix asphalt; volumetric properties; waste paper fiber.

1. Introduction

Stone Matrix Asphalt (SMA) mixtures were invented in Germany in the 1960s. Split mastic asphalt is also known as Stone Mastic Asphalt in Europe and Stone Matrix Asphalt in the United

States. These asphalt mixtures were designed to provide a mixture with the greatest resistance to studded tire wear [3-5]. SMA is a gap-graded asphalt mixture designed to increase rutting resistance, durability and improved resistance to reflective cracking when compared to dense-graded mixes [5-7]. The structure's composition of SMA consists of three parts: a coarse aggregate skeleton, a mastic, and air voids [2], as can be seen in Figure1. However, there is a fourth part that can be considered, namely, stabilizer materials. Stone-on-stone contact is provided by the coarse aggregate skeleton, resulting in high deformation resistance. The mastic is made up of fine aggregates, filler, and a significant amount of binder [8].

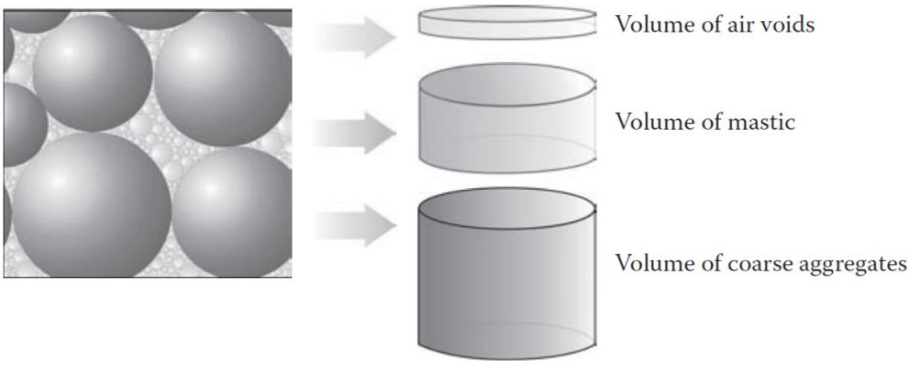

Figure 1 Division of SMA into basic components [2]

SMA offers numerous benefits, including high rutting resistance, excellent low-temperature performance, improved macrotexture, long service life, low tire noise, less water spray from tires, and poor light reflection on rainy nights [4, 9-12]. SMA is typically composed of 70–80% coarse aggregate, 8–12% filler material, and 6–8% binder [13, 14]. Because of the gap graded nature of the mixture and the high amount of binder, drain down of asphalt binder has been regarded as the main problem in constructing and placing this type of asphalt mixture [15]. To prevent this problem, the use of some additives may be necessary. Fibers and polymers are the two most common types of additives found to improve these mixtures [15]. Polyester, mineral, and cellulose fibers are some examples of fibers [16]. The incorporation of fibers into a binder or bituminous mixtures ensures their mechanical strength and stability [17]. A sufficient amount of fibers alters the properties of the asphalt, reduces penetration and increases softening point, it also changes the viscoelasticity state of the bitumen [18]. Furthermore, adding fibers to asphalt concrete leads to an increase in its dynamic modulus, which strengthens the mastic and decreases its thermal susceptibility as well, improving material strength, fatigue behavior, and ductility [19]. Moreover, fibers reduce binder drainage while increasing moisture sensitivity and compressive strength in SMA mixtures [20-22]. In contrast, a polymer is frequently used in asphalt mixtures to significantly improve mechanical properties, decreasing binder drain down [23-25]. Based on the designer's vision, various polymers (such as styrene-butadiene-styrene (SBS), ethylene-vinyl-acetate (EVA), polyethylene, or polypropylene) may be used to achieve the desired mixture properties [26, 27].

However, reviewing previous research on the effect of polymers and fibers on the performance of SMA mixtures disclosed: Al-Hadidy and Yi-qiu [28] investigated the effect of Low-density polyethylene (LDPE) on SMA mixtures, followed by laboratory tests such as Marshall, moisture sensitivity, and low-temperature cracking to evaluate the performance of constructed SMA samples. Their findings indicate that LDPE could effectively reduce binder drain down and improve the properties of asphalt binder as well as SMA mixtures; 6 % LDPE was found to be the best dosage for constructing SMA mixtures. Kumar et al. [29] studied SMA mixtures that were enriched with various fibers (natural and synthetic) and crumb rubber. According to his findings, natural fiber was comparably better than patented fiber in Marshall stability, rutting, and flexural fatigue tests; however, natural fiber resulted in a better condition in terms of asphalt concrete ageing. Furthermore, crumb rubber demonstrated greater efficiency in improving the properties of SMA compared to the fibers. Tayfur et al. [30] investigated the rutting performance of SMA mixtures modified with various additives such as amorphous polyalphaolefin, cellulose fiber, polyolefin, bituminous cellulose fiber, and styrene-butadiene-styrene. The main findings of this study were that SBS had the highest resistance to permanent deformation and fibers had the least improving effect among different used additives. Behbahani et al. [31] constructed SMA mixtures using various fibers. According to this study, German cellulose fiber had a greater effect on the properties of SMA mixtures than Iranian cellulose and mineral fibers. Pasandín et al. [32], Chew et al. [33] studied the influence of Paper fiber on properties of asphalt mixture, they concluded that using these materials as fillers increases the viscosity of asphalt mastics, Marshall stability, and the stiffness modulus, as well as improving the resistance to rutting of asphalt mixtures by increasing the adhesion between asphalt binder and aggregate.

In the design and preparation of SMA mixtures, the volumetric parameters are the direct controlling indicators. The air voids percentage in mineral aggregate for the bituminous mixtures (VMA) were determined early in the hot-mix-asphalt (HMA) mix design procedure and were maintained throughout the mix-design procedure. The volume occupied by the effective asphalt content and the air voids is included in the VMA. This volumetric property is related to mechanical properties [34-36], for example, a low percentage of air voids in bituminous mixtures (VV) will cause bleeding, whereas a high VV will cause water damage or instability in asphalt pavement. In addition to size gradation, VMA is one of the most important HMA design criteria for achieving long-term pavement durability, and it has a significant impact on the permanent deformation and fatigue performance of a compacted mix [37, 38]. The use of VMA criteria for mix design is a time-honoured and relatively successful technique. VMA requirements for HMA mixtures were first developed in the 1950s and were regarded as one of the most important volumetric parameters for HMA and SMA mixtures. Other VMA influence factors, such as aggregate factors and volumetric basis, were then highlighted, and VMA specifications were strongly emphasized during the asphalt mixture design and analysis process[39-41].

The primary goal of this research is to conduct a laboratory investigation on SMA mixtures containing recycled polymers and waste fibers, following a volumetric and mechanical approach to determine the effect of different additives on the SMA mix performance.

2. Materials

2.1 Asphalt

The bitumen used in this study was supplied from the Al-Nasiriya refinery plant. Its penetration grade is 40/50 that is commonly adopted in the middle and south of Iraq. The physical properties of neat asphalt (B0) are represented in Table 1.

Table 1 Physical properties of neat (B0).

property	**specification**	**amount**	**SCRB requirements**
Penetration, 25℃, 0.1mm	ASTM D5-D5M [42]	42.8	40-50
The softening point, ℃	ASTM D36-95 [43]	44	-
Ductility, 25℃, cm	ASTM D113-07 [44]	143	>100
Flash point, ℃	ASTM D92-05 [45]	355	>232
Specific gravity	ASTM D70-09 [46]	1.03	-
Rotational viscosity	ASTM D4402 [47]	860	≤ 3000
LOSS ON HEAT			
Penetration aging index (PAI)	ASTM D1754/D1754M [48]	0.76	-
Softening point index (SPI)	[49], [50]	4.6	-

2.2 Aggregate

The aggregate used to fabricate SMA mixtures were crushed limestone aggregate that was supplied from Karbala quarries. This type of aggregate is widely used in the asphalt paving industry, both nationally and locally. the physical properties and gradation of aggregate used are summarized in Tables 2 and 3. The gradation was selected to satisfy the requirements of AASHTO M325 in terms of ensuring the voids in coarse aggregate of the compacted mixture (VCA_{mix}) and the voids in coarse aggregate in dry rodded condition (VCA_{DRC}).

Table 2 Gradation of SMA mixture as recommended by

Sieve (mm)	Size (in)	%Percent passing	% of Passing/ Selected Gradation
19.0 mm	[3⁄4 in.]	100	100
12.5 mm	[1⁄2 in.]	90 – 100	93
9.5 mm	[3⁄8 in.]	50 – 80	60
4.75 mm	[No. 4]	20 – 35	25
2.36 mm	[No. 8]	16 – 24	18
0.075 mm	[No. 200]	8 – 11	9

Table 3 Physical properties of coarse and fine aggregates.

Aggregate's properties testing	ASTM Specifications	Results		requirements	
		coarse	Fine	coarse	Fine
Bulk specific gravity of coarse aggregate(gm/cm³)	C127 [53]	2.59		-	
The bulk specific gravity of fine aggregate (gm/cm³)	C128 [53]		2.641		-
Water absorption of coarse aggregate (%)	C127 [53]	2.25		5 max	
Water absorption of fine aggregate (%)	C128 [53]		2.41		
Los Angeles abrasion value (%)	C131 [54]	25.5		30max	
percentage of fractured particles in one side, %	D5821 [55]	100		100	
percentage of fractured particles in two sides, %	D5821 [55]	95			90

2.3 Mineral filler

The mineral filler's role is primarily to harden the rich binder of SMA. A firm mastic with bitumen fastener and settling added substance is intended to fill voids and improve structure. It strengthens the blend's attachment, resulting in a significant increase in shear strength. The high level of filler may cause the blend to solidify unnecessarily, making it difficult to deficit to mix and possibly resulting in a split of the weak blend. When all is said and done, the amount of material passing through the 0.075 mm sifter accounts for 8–12% of the total amount of material in the blend [51]. In this study two types of fillers were used in a compound form: one is Conventional Mineral Filler (CMF) and the other is Hydrated Lime (HL). The CMF generally represents the remaining material on the pan after the screening process of the used aggregate. While HL had been gotten from the Furat Lime Plant, Karbala. An amount of 1.5% from total aggregate weight was adopted from HL as a filler in this study as recommended by GSRB R9 specification [52]; Fillers properties are displayed in Table 4.

Table 4 Physical and chemical properties of used fillers.

Filler type	Chemical properties							Physical properties	
	Oxide/ Concentration								
	Sio_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	**Density (g/cm3)**	**Surface area (m2/Kg)**
CMF	81.89	3.78	1.92	7.37	3.45	0.73	0.19	2.650	223
HL	0.89	----	2.25	90.58	3.60	0.58	1.00	2.300	1240
* Chemical and physical tests of fillers were conducted in the University of Technology/ Materials Engineering Department									

2.4 Stabilizing additives

Stabilizing additive must be used to keep the binder in the SMA mix during mixing, transporting, and placement operations. To prevent the unacceptable drain down, fibers or polymers as stabilizing additives can be added to the mixture [56-59], in the current study, recycled low-density polyethylene (R-LDPE) and waste paper fiber (W-PF) are used as stabilizing additives. These two materials are described in detail below.

2.4.1 Recycled -Low-Density Polyethylene (R-LDPE)

LDPE is a type of polyethylene material that comes from the polymerization process of ethylene that is forming a long chain from one monomer [60, 61], it is the main content of nowadays facilities, such as goods bags. R-LDPE is characterized by its availability and low cost, as can get it from the recycling of bags of domestic goods after becoming a solid waste. The use of R-LDPE has been found to aid in the reduction of problems associated with deformations due to its unstable crystallization property, which leads to an improvement in asphalt rigidity. In general, the use of such materials aids in the reduction of cracking at high and low temperatures, the improvement of mixture hardness, the increase of mixture fatigue resistance, and the reduction of water damage problems [28, 62]. The used R-LDPE in this study was supplied from recycled materials obtained from a small factory in Karbala where the shopping bags are recycled. Figure 2 displays the form of R-LDPE, and Table 5 shows the physical properties of the R-LDPE modifier supplied by the same plant.

Figure 2 Used R-LDPE polymer material.

Table 1 Physical properties of waste- low-density polyethylene (R-LDPE).

Properties	Amount
Density (g/cm^3)	0.91
Tensile strength (MPa)	8.5
Tensile elongation (%)	>350
Melting temperature (◦C)	110
Flexural modulus (MPa)	7.2
Hardness shore D	45

2.4.2 Waste-Paper Fiber (W-PF)

W-PF represents a type of cellulose fibers, comes from the recycling process of the waste papers that are widespread locally. Therefore, it is suggested as a way to sustainability, which helps in reducing the pollution problems of environmental and human health. The presence contains high content of CaO and SiO_2, (Table 6) which increase the stiffening rate resulting in stiffer mastics which allows strengthening of the aggregate-binder bond and improve effective strength properties of asphalt mixture. They were shredded with a size of 3-12 mm was adopted in this study, as can be seen in Figure 3.

Figure 3 Shredded waste paper fiber.

Table 6 Chemical Analysis of W-PF

Chemical compositions	(%)
CaO	37.35
SiO_2	5.011
MgO	0.696
Al_2O_3	3.431
P2O5	0.0443
SO3	0.1869
Cl	0.0420
K_2O	0.0740
TiO_2	0.126
MnO	0.0126
Fe_2O_3	0.3959
CuO	0.0181
ZnO	0.0339
SrO	0.0308
ZrO_2	0.0165
LOI	52.52

3. Experimental Work

3.1 Preparation of Modified Asphalt

In this study, three modified asphalt binders were prepared: the first, by combining neat binder with 3% R-LDPE individually, the second with three dosages of W-PF individually, where the third with 3% R-LDPE and three dosages of W-PF collectively. The three dosages of W-PF were 0.3%, 0.5%, and 0.7% by total weight of bitumen were adopted here as used by previous studies[63]. It is worth mentioning that the AASHTO M325 recommended more than 0.3% by the total mix when the dry mixing process is used, however, this study confirms the validity of lower dosage when the wet mixing process is adopted. While for R-LDPE, one dosage of 3% by total weight of bitumen was used because it has been remarked as the better dosage by other researchers like Al-Busaltan et al. [64], Mahdy et al. [65], Abduljabbar et al. [66]. The third modification way is done by using the Mix Contents (MC) from the aforementioned modifiers with dosages equal to 3.3 %, 3.5 %, and 3.7 %. The preparation begins by heating the B0 (neat asphalt) in an oven at 170 °C for one hour to make it fluid enough for mixing then the modifiers are added gradually, then for one hour, a shear mixer with a 3000-rpm rate was used to prepare the modified binders [67].

Figure 4 Shear mixer device.

3.2 Volumetric Properties

Volumetric properties must be determined because they are fundamental standards in the mix design. AASHTO R46 [68] and AASHTO T166 [69] were used to calculate volumetric properties such as the compacted mixture's bulk specific gravity (Gmb), air voids (Va), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA).

3.3 Marshall Stability and Flow Test

Marshall stability and flow tests were carried out to determine the resistance of asphalt mixtures to distortion, displacement, retardation, and shear stress following ASTM D6927 [70], the stability test determines the maximum load that the specimen can withstand. Essentially, the applied test load is gradually increased, after which the loading is terminated and the maximum load is recorded as Marshall stability, while the vertical associated displacement is recorded as Marshall flow. Moreover, the ratio of Marshall Stability to Marshal flow is calculated as in index named Marshall stiffness.

4. Results and Discussion

4.1 Bulk Density

The bulk specific gravity of SMA mixtures with various additives and additive contents is shown in Figure 5. When compared to the control mixture (CM), the density values increased slightly when the asphalt was modified with R-LDPE polymer. This return to the network properties of R-LDPE polymer that resulting in more blocked air voids. This could refer to the higher viscosity of asphalt with R-LDPE polymer that leads to a rise in both required mixing and compaction temperatures to achieve 100% aggregate coating. In other words, low viscosity helps in the mix component packing that results in higher density. Ahmad and Technology [71] indicated a result similar to that obtained here.

Moreover, results indicate that the comprising of W-PF further to R-LDPE increase the density of these SMA mixtures. The highest bulk specific gravity values were found in the SMA mixture containing 0.3% W-PF, and the mixture containing 0.7% W-PF had the lowest values. Where the bulk specific gravity values were found ranging from 2.287 to 2.257. This behavior is related to the increment of viscosity level with respect to the W-PF content. As the continuous increment will reduce the mixture lubricity and make it stiff, then result in a decrease in the mixture density consequently. Sheng et al. [4] in their study indicated a result similar to that obtained here.

Figure 4 also displays that the use of MC demonstrates the same trend of reduction into density levels with the increment into MC. This behavior is related to the increment of binder viscosity level to the W-PF content. As the continuous increment reduces the mixture lubricity and makes it stiff, then result in a decrease in the mixture density, consequently. Punith and Veeraragavan [72] and Ahmadinia et al. [73] agreed with a similar trend for decreasing mixture density as viscosity increases.

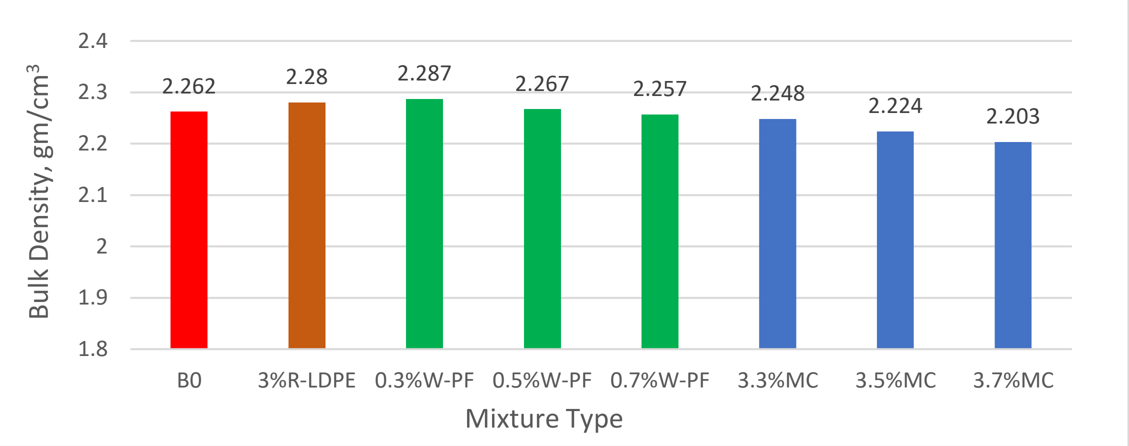

Figure 5 Bulk densities of unmodified and modified SMA mixtures.

4.2 Air Voids

Figure 6 shows the amounts of air voids in SMA mixtures with various additives. Results demonstrate that there is a noticeable variation in the level of air voids with the utilization of the different modifiers. Adding 3% R-LDPE resulted in a decrease in the amount of air voids to about 18% compared to the control mixture (B0). This is related to a reduction in the viscosity (as can be seen in a previous study conducted by the authors [74]) due to an increase in mixing and compaction temperature to guarantee complete aggregate coating and a reduction in air voids, as a result. As a result, the Marshall Stability value will improve, as stated by Ahmadinia et al. [73].

The SMA mixtures comprising W-PF show a reverse relationship between air voids and paper fiber content. Where the observed results show that the air voids level tend to rise with respect to the rising into W-PF content, and the amount of rising reached 8% after comprising 0.7% W-PF. This potential is due to the porous nature of W-PF that is working on absorbing more lightweight asphalt molecules. Besides, the high viscosity level of asphalt after the incorporation of W-PF (as can be seen in a previous study conducted by the authors [74]), which help together increase the amount of air voids consequently. Sheng et al. [4] showed a similar trend for the increase in mixture air void with increasing fiber content.

Furthermore, results display that the usage of the MC between R-LDPE and W-PF show higher increment into air voids level between (20-70) %. This is related to the higher surface area resulting from the comprising of both modifiers (i.e., R-LDPE+W-PF) contacting with asphalt, which leads to high viscosity values. That is work on absorbing more lightweight asphalt then work on increasing the amounts of air voids.

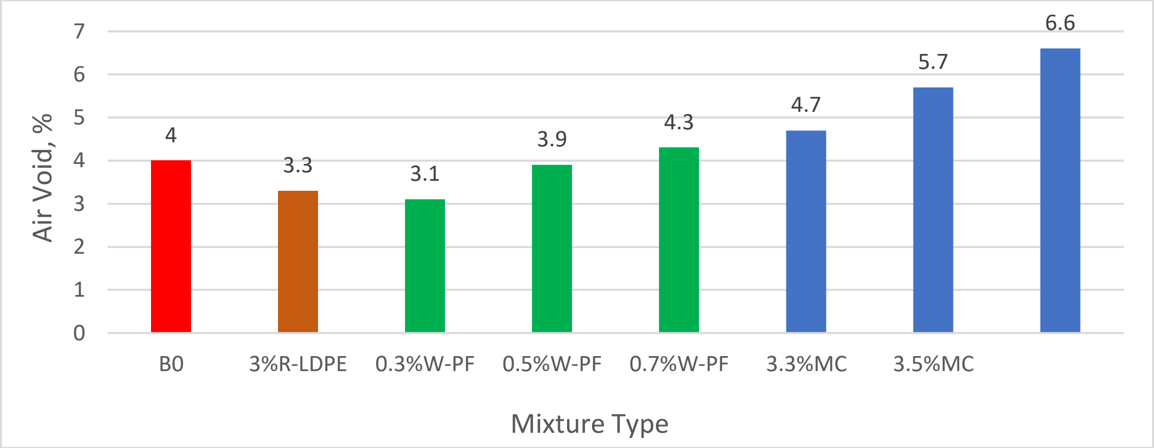

Figure 6 Air voids of unmodified and modified SMA mixtures.

4.3 Voids in the Mineral Aggregate and Voids Filled with Asphalt

Figure 7 illustrates the VMA trend of SMA mixtures with various additives. In general, the results show that the influence of modifiers has a positive impact on the amounts of VMA in terms of W-PF and MC modified SMA mixtures. Whereas the incorporation of R-LDPE polymer achieves a slight reduction. Where the comprising of W-PF shows slight improvement into VMA values as the increase in its content by no more than 1% at 0.7% W-PF compared to B0 mixture. Besides, the use of MC offers better enhancement reached 11% at 3.7% MC in contrast with the B0 mixture. In terms of R-LDPE modified SMA mixture, the resulted trend attributed to that when adding R-LDPE polymer resulted in more blocked air voids due to its network properties. Meanwhile, the amounts of VFA increased consequently, then this led to an increase in the amount of effective asphalt binder coating aggregate, and as well the VMA was reduced, as seen hereafter due to aggregate packing.

While, in the case of W-PF, the increment into VMA appeared gradually concerning W-PF dosage. As the amount of fiber increased, this lead to absorb more asphalt binders, and as a result, work on decreasing the VFA. Then help to increase the amount of effective binder film coating aggregate, thereafter, the trend of VMA appeared as indicated by Figure (7). The same behavior is offered by the usage of the MC modifier, as the incorporation of the two modifiers causes high asphalt absorption due to its higher surface area. Then making the amounts of VFA decreased more than the individual case, and as well the VMA increased more as mentioned earlier.in other words, the modifiers work as a stabilizer to the binder.

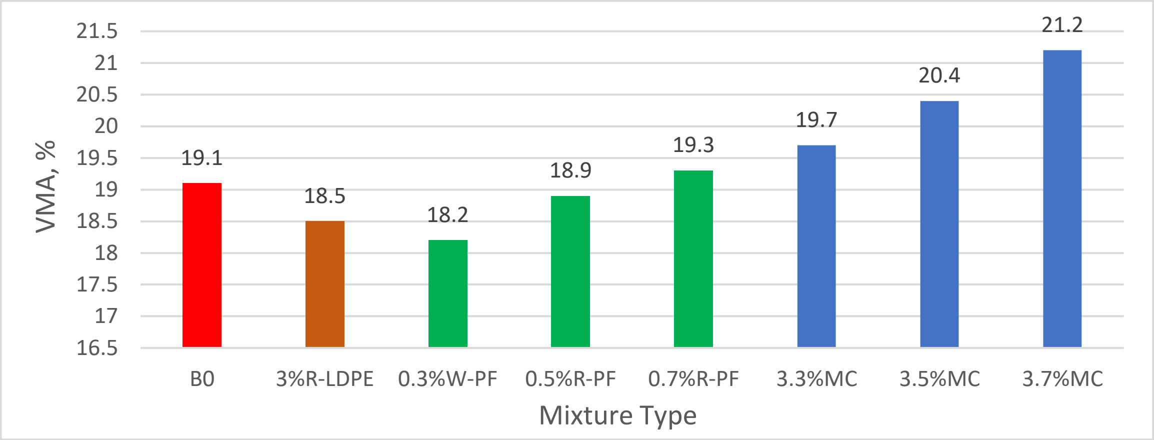

Figure 7 Voids in mineral aggregate of unmodified and modified SMA mixtures.

Figure 8 offers the percentage of voids filled with asphalt (VFA) in SMA mixtures with varying additives. Additive types and contents had a clear impact on VFA. Figure 8 shows that adding R-LDPE lead to an increase in VFA when compared to the B0 mixture. The same pattern was noticed by Ahmad and Technology [71]. While, the addition of W-PF and MC show a gradual reduction in the percentage of VFA by about 1% and 12% at 0.7% W-PF and 3.7% MC, respectively. The reduction in the amount of VFA is due to the addition of modifiers, which absorb a portion of the bitumen, increasing its viscosity, and finally reducing the VFA space. However, the comprising of R-LDPE polymer shows a slightly rising of no more than 5% compared to the B0 mixture. This is related to the network properties of polymer that work on blocking more air voids then lead to increase VFA as mentioned earlier.

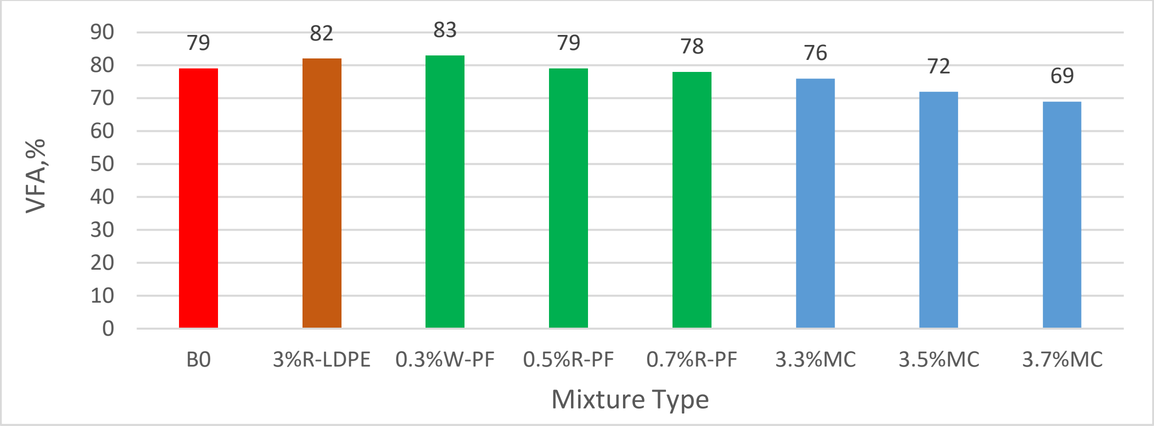

Figure 8 Voids filled with asphalt of unmodified and modified SMA mixtures.

4.4 Marshall Stability

Figure 9 summarizes the results of the Marshall Stability tests. Generally, results show that Marshall Stability (MS) values of the modified SMA mixture appeared high when compared to the control mix. It can be seen that adding 3% R-LDPE results in an increment in MS of about 8% compared to the B0 mixture. This due to the increase in the adhesion characteristics between aggregate-asphalt interface, also increases the cohesion between asphalt molecules as a result of the network reinforcement of polymer[75]. This finding is consistent with that observed by Ahmadinia et al. [73].

Moreover, results show that SMA mixtures containing W-PF give more stability. Where the maximum stability is achieved by adding 0.5% W-PF by about 70% in contrast with the B0 mixture. This return to the increase of the adhesion properties between asphalt and aggregate due to the adhesive effect of CaO and SiO_2 particles in the chemical composition of W-PF as shown in Table 6. This return to the network properties of this material that is working on increasing the cohesion between the asphalt molecules itself, as well as, increases the adhesion between the aggregate particles and asphalt binder. Besides its role in increasing the binder viscosity to W-PF content. Consequently, the asphalt film thickness that coating aggregate increase, which in turn lead to improving the mixture stability. As well, it can be seen that the trend of improvement began to decrease after increasing the amount of W-PF to more than 0.5%. This is due to the porous nature of W-PF to some extent, which works on increasing the absorption of the lightweight molecules of the asphalt binder. Then resulted in a slight reduction in the adhesion properties that in turn reflected on the mixture stability [76]. This finding is nearly identical to Mojabi et al. [77]. However, it is believed that the main reason for redaction is back to increase the air void, as can be seen in Figure 5. However, the result of combining R-LDPE and W-PF exhibits reverse behavior at high dosages as represented by Figure 9. As the rate of mixture stability reduced gradually until reached an improvement of not more than 5% at 3.7% MC compared to the B0 mixture. This is attributed to the high surface area of the MC blend that is work on occupying a high amount of asphalt's weight.

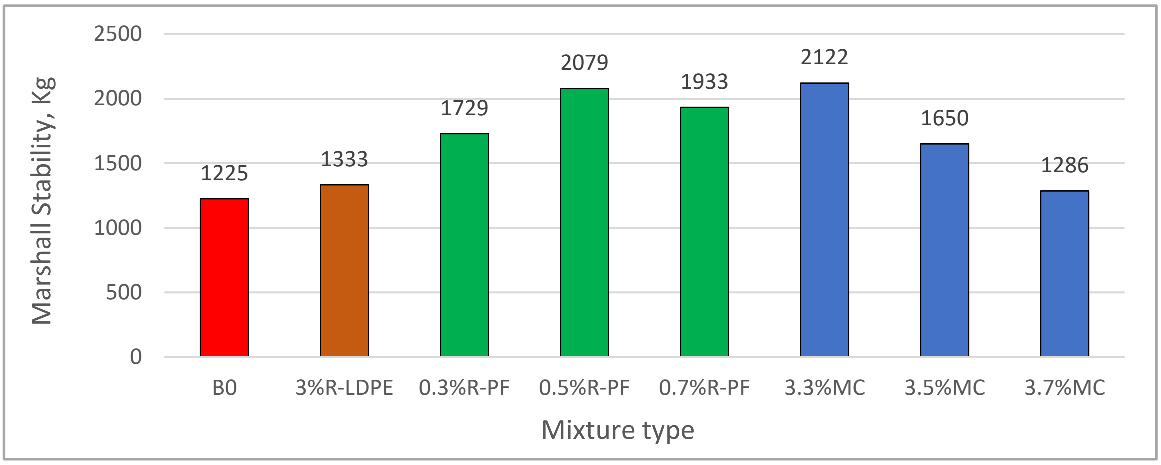

Figure 9 Results of Marshall Stability Test for Control and Modified Mixtures.

4.5 Marshall Flow

The flow of SMA mixtures with varying additives is disclosed in Figure 10. Due to the hardness of the mixtures (increase the binder stiffness), flow values show a noticeable decrease after the addition of R-LDPE by approximately 31%. This finding is consistent with Al-Hadidy et al. (2009). Figure 9 also indicates that increasing the W-PF causes the flow value to decrease slightly to about 36% compared to the B0 mixture. Then begin to increase again by approximately 26% compared to the B0 mixture, as a result of the inverse effect of air void increment. These results agree with that observed by Mojabi et al. [77]. The combination of the two modifiers may reduce the ability of mixtures to flow when loaded lower than the individual case, but show an increment for MC dosage, for the reason same as that mentioned above.

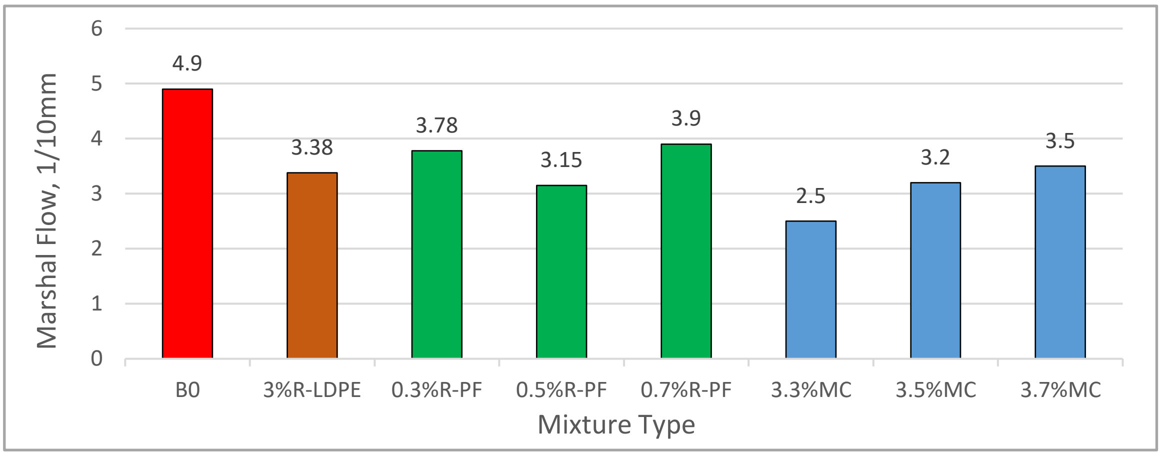

Figure 10 Results of Flow for Control and Modified SMA Mixtures.

4.6 Marshal Modulus

Figure 11 summarizes the results of a Marshall coefficient test performed on various mixtures. Figure 11 demonstrates how the use of additives increases somehow the stiffness modulus of SMA mixtures. Generally, all of the modified SMA mixtures provide significant improvements in contrast to control mixture B0. In the case of R-LDPE polymer, it can be seen that adding 3 % R-LDPE results in a 37 % increase in Marshal modulus when compared to the B0 SMA mixture. This means that R-LDPE has a positive effect on improving the resistance of the asphalt mixture to plastic flow effort. This could be due to the 3D-network formation by R-LDPE polymer, in addition to the formation of asphaltene rich phase. Which then works to increase the mixture compatibility and make it more stable.

Furthermore, the results show that SMA mixtures containing W-PF are more stable. In comparison to the control mixture, the maximum stability was achieved by adding 0.5 %W-PF by approximately 62 % improvement. This behaviour is attributed to the presence of CaO and SiO2 that gains asphalt its rigidity properties. Besides the higher viscosities of W-PF modified asphalt and the network properties of the mentioned modifier.

Furthermore, the results shown in Figure 10 show that when the two modifiers were combined, the rate of mixture stability gradually decreased until it reached 31 % at 3.7 % MC when compared to the control mixture. This is due to the MC blend's high surface area, which is working to absorb a large portion of the asphalt's weight. Reduce the required adhesion between aggregate and asphalt, which contributes to a reduction in mixture stability.

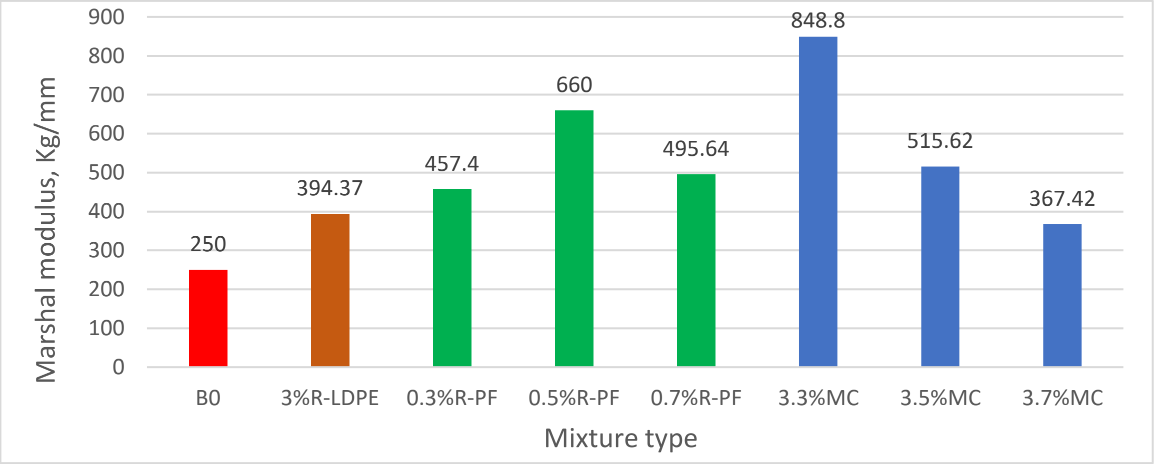

Figure 11 Results of Marshall modulus for Control and Modified SMA Mixtures.

5. Conclusion

SMA is a type of pavement mixture that is made up of aggregates, fillers, binders, and stabilizers. To achieve the best mechanical performance, these loose materials are mixed by controlling the volumetric properties which reflect on mechanical properties. Thus, in design and construction practice, volumetric properties are direct indicators. This paper investigated the effects of sustainable materials on the volumetric parameters, besides Marshall Stability, and flow (mechanical performance) of SMA mixtures. However, the following can be concluded as a summary of implementing the methodology of improving the SMA using waste and recycled materials:

1. Bulk densities of modified SMA mixture increase slightly with incorporating 3 % R-LDPE, simultaneously decrease slightly with 0.7% W-PF to about 0.2%, while adding MC decreases it significantly to 3% at 3.7%.
2. Air void for SMA mixtures comprised 3% R-LDPE and 0.3%, 05%, and 0.7% W-PF decrease approximately 17.5 %, 23 %, and 3 %, respectively. Simultaneously the 0.7 % W-PF raises void to 7%, while 3.7 % MC raises void to 40%.
3. Incorporating high doses of W-PF and MC into the SMA mixture results in a 1% and 10% increase in voids in mineral aggregate, respectively, while adding fixing R-LDPE results in a 3.1% decrease.
4. Voids filled with asphalt in SMA asphalt at 3% R-LDPE increases to 4%, while the incorporation of high doses of W-PF and MC decreases to 1.3 % and 12 %, respectively.
5. Marshall stability with 3.3% MC results in a significant increase, followed by 0.5 % W-PF and 3% R-LDPE, with increases of 42 %, 69 %, and 8%, respectively.
6. Marshall flow of SMA asphalt mixtures is decreased in all modified mixtures, to 31%, 20%, and 28% at 3% R-LDPE, 0.7% W-PF, and 3.7% MC, respectively.
7. The Marshall modulus with the addition of sustainable materials improves as an increase up to 37%, 49%, and 31% at 3% R-LDPE, 0.7% W-PF, and 3.7% MC, respectively.

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تأثير البولي إيثيلين منخفض الكثافة المعاد تدويره ونفايات ألياف الورق على مصفوفة الاسفلت الحجري

الخلاصة: *تبحث الدراسة الحالية في آثار البولي إيثيلين منخفض الكثافة المعاد تدويره (R-LDPE) وألياف نفايات الورق (w-PF) على أداء الخلائط الإسفلتية المربوطة ومصفوفة الحجر (SMA). تم فحص تأثير W-PF و R-LDPE بشكل فردي وجماعي على كل من الخصائص الحجمية (الكثافة الظاهرية ، الفراغات الهوائية ، الفراغات في الركام المعدني ، والفراغات المملوءة بالإسفلت) والخصائص الميكانيكية (استقرار مارشال ، التدفق ومعامل مارشال). تمت إضافة ألياف W-PF إلى خلائط SMA بنسب مختلفة من 0.3٪ و 0.5٪ و 0.7٪ ، بينما تمت إضافة 3٪ من R-LDPE لتحسين أداء خليط الأسفلت. أظهرت النتائج أن دمج كل من R-LDPE و w-PF في رابطة الأسفلت له تأثير إيجابي على أداء الخليط ولكن بمستويات مختلفة. أدت المعدلات الجماعية إلى زيادة الفراغات الهوائية والفراغات في الركام المعدني واستقرار مارشال ومعامل التنظيم بنسبة تصل إلى 15٪ و 3٪ و 42٪ و 70٪ على التوالي عند 3.3٪ MC (مزيج الإضافات الجماعية) بالمقارنة مع التحكم SMA. أظهرت النتائج أيضًا انخفاضًا في الكثافة الظاهرية ، وتملأ الفراغات بالإسفلت وتدفقها إلى مستوى 0.6٪ و 4٪ و 49٪ على التوالي. يشير هذا إلى أن استخدام النفايات والمواد المعاد تدويرها ، خاصة في الشكل المشترك ، يوفر نهجًا مستدامًا لتحقيق الاستقرار في رابطة الأسفلت لخلائط SMA.*