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Enhancing Stone Mastic Asphalt through the Integration of Waste Paper and Cement Kiln Dust

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Abstract: In the realm of civil engineering and industrial construction, the infusion of waste materials into road pavements has emerged as a pivotal strategy for augmenting the attributes of asphalt mixtures while concurrently mitigating the environmental repercussions associated with waste. This investigation delineates a dry method for the preliminary treatment of waste paper, preceding its amalgamation into asphalt mixtures. The focal point is the incorporation of waste paper and Cement Kiln Dust (CKD) as modifiers in Stone Mastic Asphalt (SMA). It is posited that the inclusion of waste paper fibers can substantially elevate the SMA's flexibility and crack resistance. Simultaneously, CKD is purported to bolster the asphalt's strength and durability through its cementitious characteristics. A series of SMA blends were formulated, integrating waste paper and CKD in varied proportions ranging from 0.2% to 1% by weight. Subsequent evaluations encompassed analyses of air voids, density, drain-down characteristics, Indirect Tensile Strength (ITS), and Marshall Stability. The outcomes revealed that the drain-down test exhibited enhancements in volumetric parameters, notably density and air voids. Concomitantly, there was a 33% increase in Marshall Stability and a 37% improvement in ITS. Additional advancements were observed in Marshall Flow, Tensile Strength Ratio (TSR), and skid resistance. In summation, this study establishes that waste paper, when appropriately treated and amalgamated with CKD, can be efficaciously utilized in SMA mixes, yielding mixtures with superior volumetric and mechanical properties. This methodology not only augments the stiffness and minimizes binder drainage but also enhances rutting resistance. Most crucially, it paves the way for sustainable and ethical practices in the reuse and recycling of waste materials.

Keywords: Stone Mastic Asphalt (SMA); Cement Kiln Dust (CKD); Indirect Tensile Strength (ITS); Marshall Stability; Waste material; Sustainable materials

1 Introduction

The development of SMA originated in Germany during the 1960s. The industrialization of SMA affords considerable resistance to wear from studded tires widespread in European countries, and it has been utilized for this purpose for more than 20 years [1]. Scientists have identified innovative methods and structures to improve the durability of bituminous mixtures in order to counteract the accelerated degradation of asphalt pavements caused by increasing traffic volumes. The SMA is a type of asphalt mixture that consists of 70-80% coarse aggregate, 6-7% binder, 8-12% filler, and around 0.3-0.5% modifiers, in terms of the total aggregate mass. The skeleton-like structure of the mixture is achieved by using a lot of gritty material. This facilitates the contact between the stones and effectively inhibits the formation of ruts.

The utilization of waste and recycled materials in construction projects is becoming increasingly popular due to the continual generation of garbage from ongoing production processes and modern lifestyles [2]. The use of these wastes as alterations in materials for building can therefore assist minimize expenses connected with disposing of these wastes in landfills, sparing the environment from pollution in the process [3]. Many asphalt researchers globally often combine asphalt binders with various changes to improve the properties and functionality of the final combination. Asphalt binder is a fragile material that exhibits viscoelastic properties, which increase the susceptibility of mixes to aging and cause their mechanical responses to be influenced by temperature and time [4].

As a result of frequent traffic loads, this action may have heightened the probability of other failures, such as fatigue and rutting. Thus, using different additives, such as pristine polymers, fibers, and ashes, including those that have been recycled, helps enhance the properties of the material and extend the lifespan of the pavement [5, 6]. Currently, waste polyethylene polymers, including low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), and their co-polymers, along with bio-oils derived from waste wood, are being effectively recycled [7]. Additionally, scrap tires are utilized to produce crumb rubber [8], while various types of fly ashes and other waste materials are also incorporated [9, 10].

Additional scholars examined the effects of incorporating fibers into asphalt to augment its characteristics [11]. Chew et al. [12] investigated the microscopic mechanical properties of an asphalt mixture that was improved by using recycled paper mill sludge using a dry technique. Using recycled paper mill sludge has been found to greatly improve the mechanical properties, including robust modulus, Leutner shear, and dynamic creep, of asphalt mixtures. The main reason for these discoveries is that the sludge from recycled paper mills functions as a lapping device, improving the mechanical characteristics and the adhesion between the binder and aggregate in asphalt mixtures. Fibers achieve efficacy by increasing tensile strength and providing adequate lateral rigidity for reinforcement. Furthermore, it helps to eliminate the occurrence of aggregate and binder segregation [13].

It is noteworthy that fibers have been proposed as a means to impede the infiltration of bitumen in situations involving substantial quantities of bitumen, such as gap-graded mixes [14]. Excessive asphalt content leads to problems with drain-down or bleeding during the entire process of production, storage, shipping, and paving activities [15, 16]. The addition of fibers and/or polymers to the asphalt mixture is the most often used method for avoiding drain-down or bleeding. This study investigates the effects of incorporating paper pulp fiber into stone-mastic asphalt to enhance its characteristics. The evaluation is conducted using the drain-down test, ITS test, water damage test, Marshall Stability test, and skid resistance test. The outcomes of the suggested design are contrasted with a conventional SMA formulation comprising of bitumen and aggregate, while SMA is shown as mixtures modified with paper pulp fibers.

Prior studies on the utilization of waste paper in asphalt mixtures have predominantly concentrated on wet procedures, disregarding the possible advantages and difficulties linked to dry procedures. Nevertheless, there exists a significant disparity, particularly in the examination of methods for drying. The current study aims to thoroughly examine the efficacy of integrating waste paper into asphalt mixtures by a dry technique, taking into account the existing gap in knowledge. Our objective is to offer useful insights that can enhance the sustainable and efficient utilization of waste paper in asphalt applications by investigating this undiscovered element.

2 Materials and Methods

2.1 Aggregates

In this study, aggregates were used to create asphalt concrete mixtures, with a nominal aggregate size of 19mm for SMA mixture gradation. Gravel, both coarse and fine, from the Karbala quarry in the middle of Iraq was used and crushed at the local asphalt concrete mix factory by a mechanical crusher. Figure 1 shows the recommended aggregate gradation limits for American Association of State Highway and Transportation Officials (AASHTO) M325 (AASHTO, 2012). Tables 1 and 2 show the aggregate gradation and the physical properties of the coarse and fine aggregates, respectively.

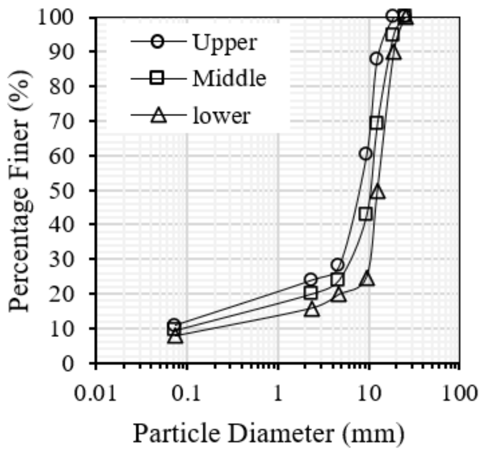

Figure 1. AASHTO M325's recommended aggregate gradation limits (AASHTO, 2012)

Table 1. Selected combining aggregate and filler grades in accordance with AASHTO M 325 specifications

Sieve Size (mm)	Passing Percentage	Selected Percentage
25	100	100
19	90-100	95
12.5	50-88	69
9.5	25-60	42.5
4.75	20-28	24
2.36	16-24	20
0.075	8-11	9.5

Table 2. Physical characteristics of both coarse and fine particles

Aggregate's Characteristic Tests	American Society for Testing and Materials (ASTM) Specifications	Results		Requirements	
		Coarse	Fine	Coarse	Fine
Bulk specific gravity of coarse aggregate $\left(\mathrm{gr/cm^3}\right)$	C127 (ASTM, 2015)	2.59			
Bulk specific gravity of fine aggregate $\left(\mathrm{gr/cm^3}\right)$	C128 (ASTM, 2015)		2.64		
Water absorption of the coarse aggregate (%)	C127 (ASTM, 2015)	2.25		< 5	
Water absorption of the fine aggregate (%)	C128 (ASTM, 2015)		2.41		
Los Angeles abrasion value (%)	C131 (ASTM, 2003)	25.5		< 30	
shattered particles on one side (%)	D5821 (ASTM, 2013)	100		100	
percentage of particles on both sides	D5821 (ASTM, 2013)	95			> 90

2.2 Filler

Two types of fillers were used in this investigation: hydrated lime (HL), sourced from the Furat Company's lime plant, and ordinary Portland cement (OPC), obtained from the Karbala Cement Plant. Their specifications were confirmed according to the Standard Specifications for Roads and Bridges (SSRB) R9 requirement (SSRB, 2003). It should be noted that 1.5% of the total aggregate weight was taken from OPC. Both materials passed through a 0.075-mm standard sieve. The laboratory properties of the fillers are displayed in Tables 3 and 4.

Table 3. Chemical compositions of fillers

Chemical Compositions	Filler Type	
	HL	OPC
Al_2O_3	-	2.325
Cao	90.586	65.147
MgO	3.602	1.327
SiO_2	0.891	25.41
K_2O	0.589	0.761
Fe_2O_3	2.254	1.125
Na_2O	1.002	1.714

Table 4. Physical properties of fillers

Property	Filler Type	
	HL	OPC
Surface area density $\left(\mathrm{m^2/kg}\right)$	225	345
Density $\left(\mathrm{gr/cm^3}\right)$	2.62	2.98

2.3 Asphalt Cement

The asphalt binder used in this study has a penetration grade of (40-50) from the Al-Nasiriya refining plant. It is frequently used in Iraq's central and southern regions. The physical characteristics of the asphalt cement are shown in Table 5.

Table 5. The physical characteristics of asphalt cement

Property	Specification	Amount	SCRB-Requirements
Penetration, 25°C, 0.1mm	ASTM-D5-D5M(ASTM, 2013a)	47	40-50
Softening point,°C	ASTM-D36-95 (ASTM, 2009a)	47	-
Ductility, 25°C, cm	ASTM-D113-07-(ASTM, 2007)	144	> 100
Flash point,°C	ASTM-D92-05 (ASTM, 2005)	355	> 232
Rotational viscosity	ASTM-D4402(ASTM, 2002a)	130-535.0 141.3-160	≤ 3000
Specific gravity	ASTM-D70-09-(ASTM, 2009)	1.03	-

2.4 Additives

2.4.1 Paper pulp fiber

Paper pulp fiber was obtained from waste paper, a form of cellulose fiber generated by recycling local waste papers that are frequently produced [17]. These materials can thus be considered a step towards sustainability, which aids in lowering polluting factors affecting the environment and people's health. In this research, paper was soaked and mixed well with a hand blender until it turned into a material like threads; then, it was dried well and ground with a small mill to obtain fibers. Figure 2 shows the paper pulp fiber.

(a) (b) (c) (d)

Figure 2. Paper pulp fiber produced in the lab

2.4.2 CKD

CKD is a waste material produced in considerable quantities during the manufacture of Portland cement. For the present study, the CKD was supplied from the Karbala cement plant. Table 6 displays the chemical composition of CKD.

2.4.3 Emulsion

An emulsion is made up of three basic components: asphalt, water, and a small amount of an emulsifying agent. These elements are added to a colloid mill device during the same procedure, which turns the asphalt into small droplets by shearing. The surface-active emulsifier maintains the asphalt droplets in a steady suspension and regulates the breaking time. The material is a liquid product that may be utilized in cold operations for building and maintaining roads and has a viscosity that ranges from heavy cream to liquid. Nitoproof 30 is a bitumen emulsion that was supplied by the FOSROC company and used as a binding agent. Table 7 displays the properties of the used emulsion.

Table 6. Properties and chemical composition of CKD

Chemical Compositions	CKD
Al_2O_3	3.35
Cao	42.8
MgO	0.89
SiO_2	15.27
K_2O	1.05
Fe_2O_3	2.3
Na_2O	0.18
Loss on ignition LOI (%)	32.46
Others	0.82

Table 7. Emulsion properties

Property	Value
Form	Dark brown liquid
Specific gravity	1.00
Solid's content	60 to 65 %
Rubber content	Approx. 10 %
Drying time	30 minutes at 25°C
Over coating time	1 hour @ 25°C

2.5 Preparation of the Materials

The bitumen used in this experiment had a penetration grade of 40 out of 50 and an average softening point of 49 degrees Celsius. The various physicochemical properties of the base bitumen are listed in Tables 2 and 3. To create SMA mixes, crushed limestone from the Karbala quarry was used as aggregate. Both locally and nationally, the asphalt paving industry extensively employs this group of materials. The aggregate's gradation and physical properties are shown in Tables 1 and 2, respectively.

The purpose of this study is to determine the suitability of a single size (fine or coarse) and a mixture of a combination of paper pulp fiber and CKD, as well as the appropriateness and homogeneity of the composite mixtures in enhancing the properties of the SMA mixture. This study used constant ratios of waste paper pulp fiber (10 grams) with constant ratios of CKD (10 grams), emulsion (50 grams), and thinner (5 grams). The components were mixed in the form of small granules and added to the aggregates in various ratios based on the weight of the SMA mixture.

2.5.1 Preparation of the additives

In this study, fixed proportions of paper pulp fiber (10 grams), CKD (10 grams), emulsion (50 grams), and thinner (5 grams) were blended at room temperature, forming small granules. These granules were then incorporated into the aggregates in different proportions relative to the weight of the SMA mixture, as illustrated in Figure 3. The corresponding percentages of these additives in the SMA are presented in Table 8.

2.5.2 Preparation of the SMA asphalt mixtures

Five SMA asphalt mixes, comprising both control and modified formulations, were created to assess the effectiveness of the additives in improving the quality of the SMA mixture. To meet testing requirements, these mixes were designed using two different types of specimens. In the first set, unaltered mixes were developed with four levels of neat bitumen ranging from 6 to 7.5 percent, with a 0.5 percent increment, to comply with specifications defining the SMA-Control mixture with optimal asphalt content (OAC) as outlined in AASHTO R46.

Figure 4 shows that 75 blows of the Marshall hammer were used on each face of specimens that were 63.5 ± 2.5 mm (2.5 ± 0.2 in) tall and 100 mm (4 in) across. This was done to get the required limit of air holes. Following AASHTO M325 guidelines, all controlled mixtures underwent examinations for air voids, voids in the coarse aggregate, drain-down, and TSR tests. Based on the output results, the combination with OAC, representing the control mixture (CM) throughout the research, was then determined.

In the second set, Ethylene Propylene Copolymer (EPC) additives were added through dry processing to make modifier mixtures with the other ingredients listed above. The combination was subsequently evaluated using specimens for its volumetric, mechanical, and functional characteristics. Table 8 demonstrates the mixture matrix of the experimental program.

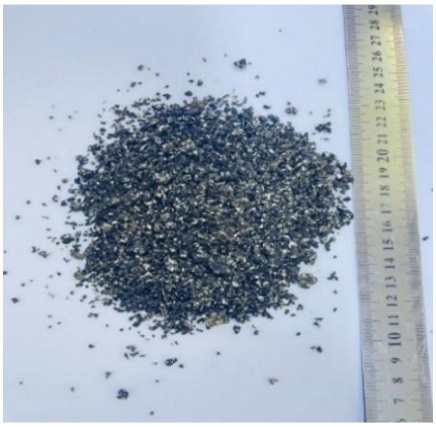

Figure 3. Materials for additives after mixing all materials (EPC)

Table 8. The additives' ratio to mixture weight

SMA Mixtures	Additives (EPC)
SMA0	0 EPC
SMA1	0.2 % EPC
SMA2	0.4 % EPC
SMA3	0.6 % EPC
SMA4	0.8 % EPC
SMA5	1 % EPC

Figure 4. Marshall specimen

2.6 Mixture Testing Methods

Several types of tests were used in this study to see how well SMA mixes worked. These included drain-down, air void, ITS, Marshall Flow and Marshall Stability, water damage, and skid resistance tests. The main focus was on volumetric, mechanical, and durability testing. These tests offer a comprehensive view of the properties of asphalt mixes, enabling engineers to optimize asphalt for improved cracking resistance, control of deformation, and durability under a variety of conditions.

2.6.1 Drain-down test (DRT)

The drain-down test is important in designing SMA mixtures due to their high asphalt content, which makes them susceptible to drainage issues, especially during mixing, storage, and compaction [18]. AASHTO M325-08 (AASHTO, 2012) recommends 0.3% as the highest permissible level of drain-down. According to this standard, the uncompacted SMA mixture sample should be transferred into the wire basket in an undisturbed form. Next, its mass, as well as the mass of a paper plate with a precision of 0.1 gram, should be determined. Then, the wire basket should be placed on the paper plate, and the assembly should be put into an oven at a specified temperature (according to AASHTO T 245, Section 3.3.1) for precisely 60 minutes. Finally, after 60 minutes, the basket and paper plate are taken out, and the mass of the paper plate should be determined to the nearest 0.1 gram. It is worth mentioning that there should not be any visible aggregate particles outside the basket. Otherwise, they should be incorporated back into the mixture without being considered a drain-down.

Accordingly, in this study, four samples were prepared for this test, each studied at two different temperatures: the estimated plant production temperature and the projected plant production, as suggested by AASHTO T305 (AASHTO, 2001). As depicted in Figure 5, the tests involve using a loose mixture placed in a typical 6.3 mm mesh basket over a pan with a known weight. Subsequently, the drain-down sample is conditioned for 1 hour ± 5 minutes in a forced draft oven, as illustrated in Figure 5. After the completion of conditioning, the sample with the basket and pan is extracted from the oven and left to cool down to room temperature. The weight of filler and separated asphalt in the pan is then calculated to determine the drain-down quantity using Eq. (1).

$$drain \ - \ down \ (\%) = \frac{D - C}{B - A} \times 100 \quad (1)$$

where:

A: the weight of the wire basket when empty,
B: the weight of the sample and wire basket,
C: the catch plate or container's empty mass, and
D: the catch plate or container's bulk + the weight of the drained material.

(a) (b)

Figure 5. Drain-down the sample and test basket from the force draught oven

2.6.2 Air void test

The amount of porosity or voids in the mix determines how long a bituminous pavement will endure. A mixture with a high porosity level that has too many voids can allow hazardous air and water to penetrate. If the porosity is too low, extra bitumen may flush out of the mixture and rise to the surface [15]. According to international standards (e.g., ASTM D6752 for volumetric properties of asphalt mixtures), an appropriate method is employed for compacting a sample of asphalt specimen, and its dimensions and mass are determined. Then, the compacted specimen is placed in a vacuum chamber. In this chamber, a vacuum is applied to the specimen to remove the air voids. After the vacuum process, the specimen's mass in the vacuum chamber is determined. Finally, using Eq. (2), the air void content is calculated as a percentage.

$$Air \ Voids(\%) = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100 \quad (2)$$

where:

G_{mb}: the bulk specific gravity of the compacted specimen

G_{mm}: the maximum specific gravity of the asphalt mix.

The test can be conducted on multiple specimens and the average air voids percentage be calculated for more accurate results.

In this study, for the air void test on the mixture, the mass of the dry asphalt specimen was measured. Then, using a calibrated volumeter or gyratory compactor, the bulk volume of the compacted asphalt specimen was calculated. Finally, the air void percentage was calculated.

With a volumeter, the compacted specimen was immersed in a liquid, and the resulting increase in liquid level gave the volume of the sample. Alternatively, for a gyratory compactor, the volume was determined indirectly by measuring the height of the compacted specimen and the diameter of the mold, with the volume calculated using the formula for the volume of a cylinder.

2.6.3 ITS test

The need to identify the ITS test for asphalt mixes, which is linked to cracking issues in asphalt mixtures, underscores the significance of this test. The ITS for asphalt mixtures is a straightforward, effective, and adaptable test with fewer variables. It has also shown potential for using ITS data to predict fatigue cracking [19].

Furthermore, one potential factor contributing to these conditions is the development of tensile strains in the pavement's bulk, manifesting as two different forms of cracks. The ITS of a sample is determined using the maximum load to failure. Fatigue cracking, known as the first type of crack, is most commonly induced by traffic loads. Similar to the first type of fracture, the second type of fracture (also known as thermal cracking or shrinkage cracking) is caused by environmental pressures [20].

According to ASTM D3967/D3967M, a cylindrical specimen with smooth, parallel ends is prepared for this test. The specimen is placed in the testing machine between steel loading platens, as shown in Figure 6, and a compressive load with a constant rate (50 mm/min) is applied slowly until failure occurs. Finally, the maximum load at failure is recorded, and the ITS is calculated using Eq. (3):

$$ITS = \frac{2P}{\pi dh} \tag{3}$$

where:

P: the fracture load

d: the diameter of the specimen

h: the height of the specimen

Figure 6. The sample in the advice of ITS

2.6.4 Marshall Stability (MS) and Marshall Flow (MF) test

The ASTM D6927 standard contains detailed descriptions of every step of the testing. It is crucial to remember that the Marshall Stability test was conducted using a load cell and a loading frame. To do so, the specimen is heated to 60 ± 1°C either in a water bath for 30–40 minutes or in an oven for at least 2 hours. The prepared specimen is put inside the Marshall Stability testing apparatus (see Figure 7), and the flow meter is adjusted to zero. Then, it was exposed to a consistent and steady increase in downward force (50 mm/min) until it reached its point of failure.

Finally, the maximum amount of force that the specimen can withstand was determined and identified as the Marshall Stability (MS) in kilonewtons (kN).

Figure 7. The sample in the advice of Marshall Stability

Once stability has been determined, the flow rate of the specimen is calculated. The specimen was placed inside the Marshall Stability testing device, and a force was applied. Finally, the deformation of the sample was recorded and labeled as Marshall Flow (MF) in increments of 0.25 mm.

2.6.5 Water damage test

The damage caused by dampness is considered one of the most distressing types because it can both exacerbate existing issues and initiate new ones. AASHTO T283 suggests a testing method for asphalt mixture susceptibility. This test contrasts the ITS of the dry specimens with the ITS of the wet-conditioned specimens as an indicator of the samples' resistance to moisture damage. Conditioned samples were immersed in water for 24 hours at 60°C, as depicted in Figure 5. The TSR must be at least 80%, and the air voids should not exceed 7% when the samples are submerged in water for 24 hours. Additionally, this recognizes that different climatic and traffic loading conditions would affect the service life of the pavement [21]. The TSR is calculated using the following formula:

$$TSR = \frac{ITS_{wet}}{ITS_{dry}} \tag{4}$$

2.6.6 Skid resistance test

Skid resistance is a crucial factor influencing the interaction between tires and pavement, significantly impacting traffic safety. As illustrated in Figure 8, the British Pendulum Tester (BPT) was employed to assess the slip resistance of SMA asphalt mixes following ASTM E303.

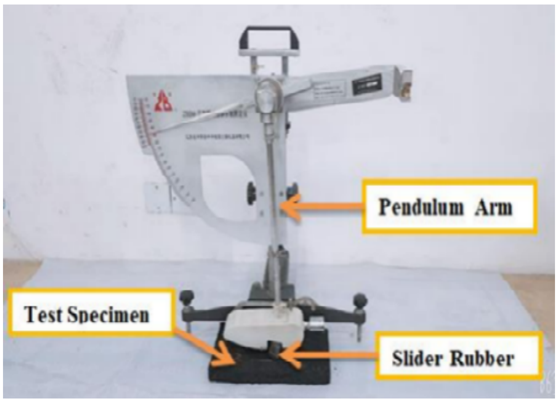

Figure 8. The British pendulum device

To ensure the accuracy of the slip resistance measurements, the BPT instrument was calibrated according to ASTM E303-18. To calibrate the pendulum swing radius, the sliding edge was set to a distance of 508 mm from the axis of rotation. The mass of the pendulum arm with the slide assembly was 1.5 kg. The center of gravity of the pendulum arm was approximately 410 mm from the axis of rotation. A synthetic rubber was used for the sliding rubber. The average vertical slide force was approximately 2500 gr.

To conduct this test, the asphalt mixture was compacted in a steel mold beneath a roller compactor, resulting in a solid block that measured 300mm in length, 165mm in width, and 40mm in thickness. Before the test was conducted, these blocks were allowed to remain in the mold for a 24-hour period at room temperature. Asphalt mixtures underwent testing in both dry and wet conditions to evaluate their skid frictional properties. Four readings were taken for each specimen in every case, and the average of these readings, representing the skid resistance of the tested object, was determined.

3 Results and Discussions

3.1 Interpretation of Air Void Test Results

Figure 9 displays the variation of the percentage of air voids in SMA mixtures with the EPC additive. There are a number of reasons for the variations in air void percentage that are seen in an asphalt mixture as the additive dosage is increased. By mixing SMA with the EPC additive at very low amounts (<0.8%), it may improve the interaction between the binder and the aggregate, making it more compact and reducing the number of air pockets. There may be an ideal percentage (0.2%) at which the additive performs best. Excessive dosage may cause an increase in void content as the dosage rises (>0.8%), for a variety of reasons. The correct distribution and interaction of components may be disrupted by problems like aggregate formation, an excess of modified binder, decreased workability, changes in rheological properties, and incompatibility. This outcome supports previous findings in the literature [22].

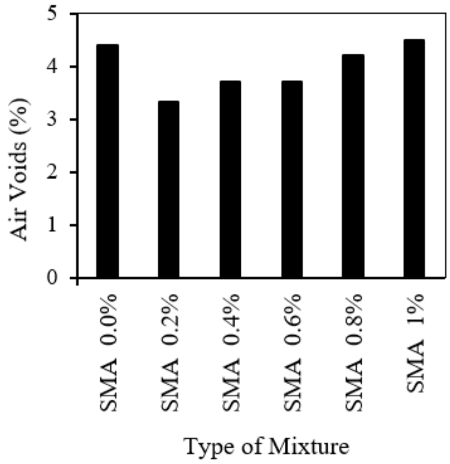

Figure 9. Air voids of the control and modified SMA mixes

3.2 Interpretation of DRT Results

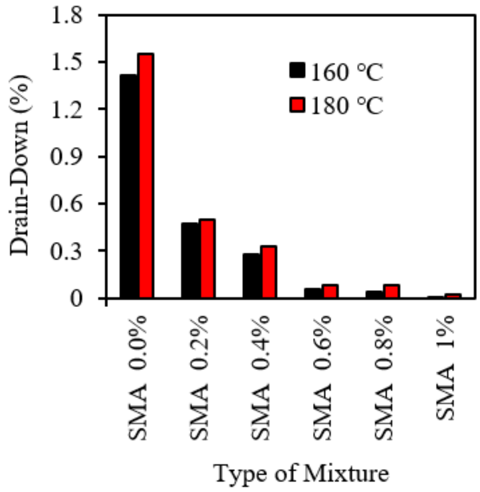

Figure 10. Drain-down of the control and modified SMA mixtures

Figure 10 illustrates the results of the drain-down test for the mixtures at various additive content percentages after an hour of conditioning in a forced-draft oven. The drain-down value for the EPC mixes was consistently lower than that of the control mixture, irrespective of the EPC amount used. Moreover, it worsened with increasing EPC content, reaching 0.01% at 160°C and 0.02% at 180°C for 1% EPC. It should be noted that 160°C and 180°C are the preheating temperatures for asphalt mixtures before conducting DRT. These high temperatures are essential to enhance the workability of the mixture and simulate field conditions. The modified EPC, employed in the combination and featuring a higher surface area due to its crystal form, may contribute to the reduction in drain-down value. However, the increased surface area needs to be moistened with binder [23], ultimately stabilizing and retaining the binder on its surface, thereby reducing binder drain. According to AASHTO T305, the acceptable drain down should be less than 0.30%. So, Figure 10 illustrates that an asphalt mixture including at least 0.6% additive had an acceptable DRT result.

3.3 Interpretation of ITS test Results

In Figure 11, you can see the values for the ITS of samples of SMA mixes with different additives added at different percentages. The samples were either conditioned or not. The results indicate that tensile strength increases by including additives in the asphalt mixture. This is likely attributed to the effective distribution of fibers in different directions within the asphalt mixture, providing robust resistance to tensile forces. This occurs because stabilized combinations tend to enhance the mixture's rigidity compared to the control mixture. Moreover, the stiffness of the mixtures rises in proportion to the additives' ability to strengthen the bond between the aggregate and binder [24].

According to Figure 11, adding 0.2%, 0.4%, 0.6%, and 0.8% of additives to the asphalt mixture increased the ITS by 14%, 16%, 18%, and 38%, respectively. However, the ITS of the mixture started to decline when the dosage of the additive was increased to 1%. This could be potentially due to issues like over-modification, workability issues, and binder dilution. These problems could weaken the mixture's cohesiveness and lower its tensile strength.

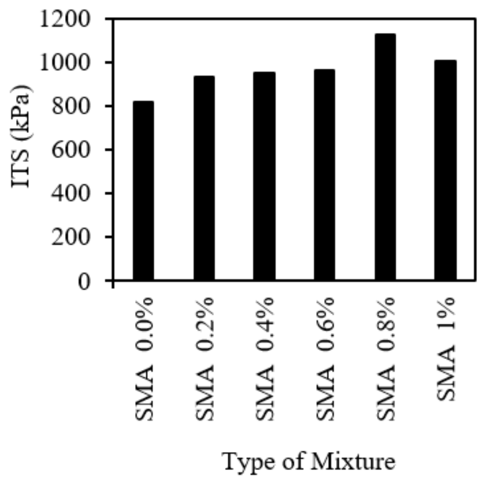

Figure 11. ITS of control and modified SMA mixtures

3.4 Interpretation of Marshall Stability (MS) and Marshall Flow (MF) Test Results

3.4.1 Marshall Stability (MS) result

The results of the Marshall Stability test are presented in Figure 12. The stability of the combination improved as the number of additives in the mixture increased compared to the control mixture. At 0.8% additive content, Marshall Stability (MS) reached its maximum value, approximately 33% higher than the control SMA. This improvement is likely attributed to the effective distribution of the modifier in various directions within the asphalt mixture, increasing cohesion between the asphalt-modified binder and aggregate, and ultimately providing resistance to permanent deformations. These findings align with those reported in the study [25].

3.4.2 Marshall Flow (MF) result

Figure 13 illustrates a noticeable decrease in flow values when the modifier was added. The mixes became less flexible, resulting in a lower flow value. The addition of paper pulp fiber and CKD to the SMA mixtures led to a reduction in the flow value, reaching the lowest point in SMA at 0.6% compared to the SMA 0 mixture. Subsequently, there was an increment caused by a decrease in the stone-on-stone contact of the mixtures.

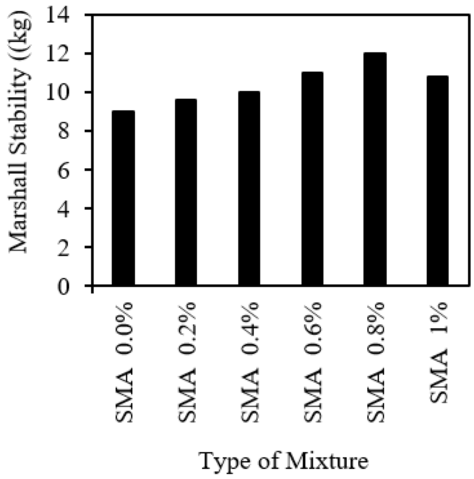

Figure 12. Marshall Stability of control and modified SMA mixtures

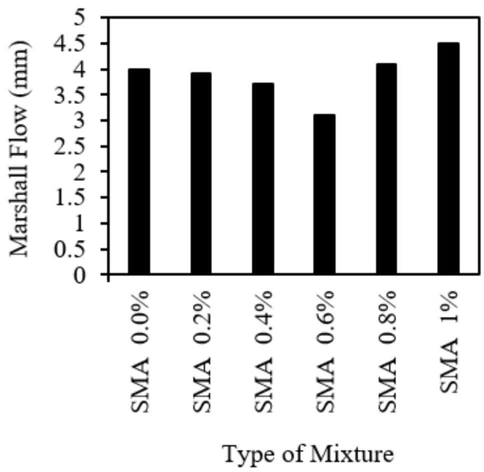

Figure 13. FM of modified and control SMA mixes

3.5 Interpretation of TSR Test Results

The TSR of the control mixture is approximately 66%, which falls below the recommended threshold of 70% as per AASHTO T283. This indicates that the control mixture is more susceptible to moisture. Figure 14 depicts the TSR values, revealing that most mixtures with EPC modifier exhibit higher TSR values than the control mixture, particularly noticeable in the case of the SMA 0.2% mixture. This is because EPC additives make it easier for bitumen and aggregate to stick together. This makes asphalt mixtures less likely to breakdown when they get wet, which increases their durability. These findings are consistent with those reported in the literature [17].

3.6 Interpretation of Skid Resistance Test Results

The excellent traction of SMA-mixed surfaces is advantageous in both dry and wet circumstances. In dry conditions, the skid resistance of the mixed surface went up significantly in all modified SMA mixtures: SMA 0.2%, SMA 0.4%, SMA 0.6%, SMA 0.8%, and SMA 1%. The increases were about 40%, 22%, 13%, 31%, and 35%, respectively. Under wet conditions, the skid resistance of the mixed surface increased by approximately 26%, 38%, 21%, 22%, and 17%, respectively (see Figure 15). This means that the asphalt binder is getting stiffer, which stops the aggregate from moving around when traffic moves, and the macro-volumetric properties of the SMA surface texture are getting better. Modifier application also enhances the characteristics of surface roughness by improving the pavement's micro-texture qualities. Increasing the tire's contact surface area with the pavement is another means of augmenting friction forces.

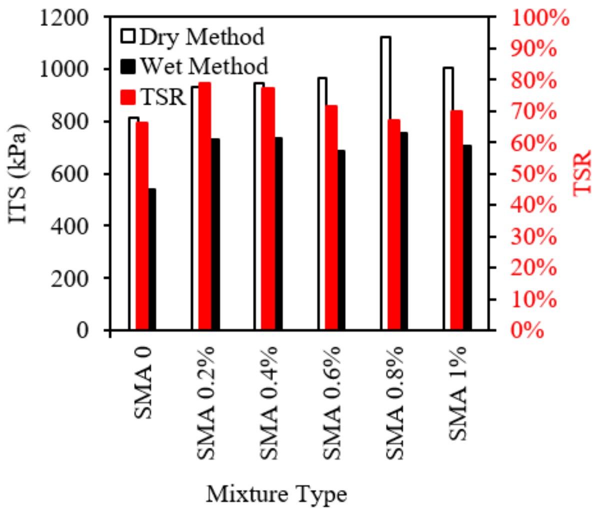

Figure 14. ITS and TSR of control and modified SMA mixture

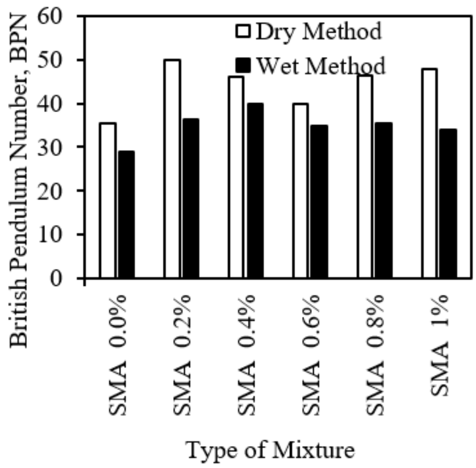

Figure 15. Test of skid resistance for the modified and control SMA mixtures

4 Conclusion

The primary focus of this study was to assess the functionality of SMA (Shape Memory Alloy) in a laboratory setting. The study utilized paper as a modifier and employed the dry method for mixing. The study examined the impact of the modification on the mechanical characteristics of SMA, including its drainage capacity, ITS, Marshall Stability, Marshall Flow, water damage resistance, and skid resistance. The important conclusions of this research can be summarized as follows, based on the acquired results:

- The volumetric and Marshall properties of SMA mixture modifiers displayed favorable patterns, indicating adherence to norms. Nevertheless, the drain-down readings for all percentages exhibited a decline to 0.01% at 160°C and 0.02% at 180°C when employing the 1% EPC adjustment.
- The Marshall Stability of the modified SMA mixture increased by 6.7%, 11%, 22%, 33%, and 20% when the EPC was changed by 0.2%, 0.4%, 0.6%, 0.8%, and 1% respectively, compared to the original SMA mixture. The flow decreased by 2.5%, 7.5%, and 22.5% when the decreases in EPC were 0.2%, 0.4%, and 0.6%. However, it began to increase again at 0.8% and 1% EPC, reaching 2.5% and 12.5% respectively.
- Utilizing EPC modifiers resulted in a rise in ITS, with the most significant enhancement seen at a concentration of 0.8% EPC.
- The TSR experienced enhancements of 19%, 16.7%, 7.15%, and 6% when the SMA mixture was modified with 0.2%, 0.4%, 0.6%, and 1% EPC, respectively. However, the addition of 0.8% EPC to the mixture had a detrimental effect on its resistance to water damage.
- The skid resistance of SMA samples with different EPC modifications was significantly higher compared to unreinforced samples.

Utilizing dry-processed blends of recycled paper and modified asphalt with CKD has the potential to enhance the durability of flexible pavement, thereby mitigating rutting damage and promoting the eco-friendly practice of recycling treated waste paper.

Experiments have demonstrated the feasibility of incorporating waste paper as a modifier in aston mastic asphalt. However, its practical application is hindered by challenges related to compatibility, consistency, durability, and potential moisture sensitivity. The diversity of waste paper properties amplifies intricacy, thus it is vital to meticulously evaluate any potential disparities between field settings and laboratory experimentation. Conducting thorough laboratory and field testing and assessments is crucial to ensure that the incorporation of waste paper meets industry standards and yields environmentally friendly and effective asphalt mixtures.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] H. Behbahani, S. Nowbakht, H. Fazaeli, and J. Rahmani, "Effects of fiber type and content on the rutting performance of Stone Matrix Asphalt," *J. Appl. Sci.*, vol. 9, no. 10, pp. 1980–1984, 2009. https://doi.org/10.3923/jas.2009.1980.1984

[2] A. Dulaimi, H. Al Nageim, K. Hashim, F. Ruddock, and L. Seton, "Investigation into the stiffness improvement, microstructure and environmental impact of a novel fast-curing cold bituminous emulsion mixture," in *6th Eurasphalt & Eurobitume Congress*, Prague, Czech Republic, 2016, pp. 1–12.

[3] S. Al-Busaltan, H. Al Nageim, W. Atherton, and G. Sharples, "Green bituminous asphalt relevant for highway and airfield pavement," *Constr. Build. Mater.*, vol. 31, pp. 243–250, 2012. https://doi.org/10.1016/j.conbuildmat.2011.12.065

[4] A. Diab, M. Enieb, and D. Singh, "Influence of aging on properties of polymer-modified asphalt," *Constr. Build. Mater.*, vol. 196, pp. 54–65, 2019. https://doi.org/10.1016/j.conbuildmat.2018.11.105

[5] S. Saedi and S. Oruc, "The influence of SBS, viatop premium and FRP on the improvement of Stone Mastic Asphalt performance," *Fibers*, vol. 8, no. 4, p. 20, 2020. https://doi.org/10.3390/fib8040020

[6] S. Saedi and S. Oruc, "Investigating the possibility of using roof shingles waste and fibers in Stone Mastic Asphalt pavements," *Int. J. Transp. Eng.*, vol. 9, no. 3, pp. 681–691, 2022.

[7] X. Yang, Z. P. You, Q. L. Dai, and J. Mills-Beale, "Mechanical performance of asphalt mixtures modified by bio-oils derived from waste wood resources," *Constr. Build. Mater.*, vol. 51, pp. 424–431, 2014. https://doi.org/10.1016/j.conbuildmat.2013.11.017

[8] S. Poovaneshvaran, M. R. M. Hasan, and R. P. Jaya, "Impacts of recycled crumb rubber powder and natural rubber latex on the modified asphalt rheological behaviour, bonding, and resistance to shear," *Constr. Build. Mater.*, vol. 234, p. 117357, 2020. https://doi.org/10.1016/j.conbuildmat.2019.117357

[9] N. Abduljabbar, S. Al-Busaltan, and A. Dulaimi, "Evaluating the mechanical properties of thin asphalt overlay incorporating reed ash," in *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 1067, no. 1, 2021, p. 012077. https://doi.org/10.1088/1757-899X/1067/1/012077

[10] A. Dulaimi, H. K. Shanbara, H. Jafer, and M. Sadique, "An evaluation of the performance of hot mix asphalt containing calcium carbide residue as a filler," *Constr. Build. Mater.*, vol. 261, p. 119918, 2020. https://doi.org/10.1016/j.conbuildmat.2020.119918

[11] S. Saedi, G. Sadeghian Asl, and S. H. Yasrobi, "The combined effect of SBS and proplast in improving the Stone Mastic Asphalt performance," *Q. J. Transp. Eng.*, vol. 10, no. 2, pp. 385–399, 2018.

[12] J. W. Chew, S. Poovaneshvaran, M. R. M. Hasan, M. O. Hamzah, J. Valentin, and A. Sani, "Microscopic analysis and mechanical properties of recycled paper mill sludge modified asphalt mixture using granite and limestone aggregates," *Constr. Build. Mater.*, vol. 243, p. 118172, 2020. https://doi.org/10.1016/j.conbuildmat.2020.118172

[13] A. Alrajhi, "Fiber dosage effects in asphalt binders and hot mix asphalt mixtures," Ph.D. dissertation, Arizona State University, 2012.

[14] E. R. Brown, "Designing Stone Matrix Asphalt mixtures for rut-resistant pavements," *Transp. Res. Board*, pp. 425–430, 1999.

[15] E. Brown, R. B. Mallick, J. E. Haddock, and J. Bukowski, "Performance of Stone Matrix Asphalt (SMA) mixtures in the United States," *Natl. Cent. Asph. Technol., NCAT Report No. 97-1*, 1997.

[16] E. R. Brown, J. E. Haddock, R. B. Mallick, and T. A. Lynn, "Development of a mixture design procedure for Stone Matrix Asphalt," *Natl. Cent. Asph. Technol. (U.S.)*, 1997. https://doi.org/10.21949/1404497

[17] A. Hameed, S. Al-Busaltan, A. Dulaimi, M. A. Kadhim, and R. Al-Yasari, "Evaluating modified asphalt binder comprising waste paper fiber and recycled low-density polyethylene," in *J. Phys.: Conf. Ser.*, vol. 1973, no. 1, 2021, p. 012237. https://doi.org/10.1088/1742-6596/1973/1/012237

[18] L. Devulapalli, S. Kothandaraman, and G. Sarang, "Effect of rejuvenating agents on Stone Matrix Asphalt mixtures incorporating RAP," *Constr. Build. Mater.*, vol. 254, p. 119298, 2020. https://doi.org/10.1016/j.conbuildmat.2020.119298

[19] N. S. Mashaan, A. H. Ali, M. R. Karim, and M. Abdelaziz, "A review on using crumb rubber in reinforcement of asphalt pavement," *Sci. World J.*, vol. 2014, p. 214612, 2014. https://doi.org/10.1155/2014/214612

[20] S. A. Hussein, Z. Al-Khafaji, T. J. M. Alfatlawi, and A. K. N. Abbood, "Improvement of permeable asphalt pavement by adding crumb rubber waste," *Open Eng.*, vol. 12, no. 1, pp. 1030–1037, 2022. https://doi.org/10.1515/eng-2022-0345

[21] M. W. Witzcak, "Simple performance test for superpave mix design," *Transp. Res. Board*, vol. 465, 2002.

[22] Y. P. Sheng, H. B. Li, P. Guo, G. J. Zhao, H. X. Chen, and R. Xiong, "Effect of fibers on mixture design of Stone Matrix Asphalt," *Appl. Sci.*, vol. 7, no. 3, p. 297, 2017. https://doi.org/10.3390/app7030297

[23] A. Mahrez and M. R. Karim, "Fatigue characteristics of Stone Mastic Asphalt mix reinforced with fiber glass," *Int. J. Phys. Sci.*, vol. 5, no. 12, pp. 1840–1847, 2010.

[24] E. Ahmadinia, M. Zargar, M. R. Karim, M. Abdelaziz, and E. Ahmadinia, "Performance evaluation of utilization of waste polyethylene terephthalate (PET) in Stone Mastic Asphalt," *Constr. Build. Mater.*, vol. 36, pp. 984–989, 2012. https://doi.org/10.1016/j.conbuildmat.2012.06.015

[25] K. K. Gazia and A. Sukhmanjit, "Use of natural fibre and binder quality in Stone Matrix Asphalt mixture," *Int. J. Latest Res. Eng. Comput.*, vol. 5, no. 3, pp. 73–78, 2017.