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An Investigation of the Performance of Stone Mastic Asphalt Mixture Subjected to Ageing

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ABSTRACT

One crucial element of the infrastructure designed by civil engineers is the highway. Stone Mastic Asphalt (SMA) is a recently developed asphalt mix that is characterized by a high amount of coarse aggregate, filler, and asphalt, setting it apart from regular dense asphalt. As fillers, 6% calcium carbonate and 2% ordinary Portland cement (OPC) were added to the coarse-graded mix to prevent stripping and reduce binder drain down. The high coarse aggregate structure contributes to the creation of a stable matrix, improving its resistance to long-term deformation. This study's primary goal is to look at how varied ageing times and temperatures affect the performance of SMA mixtures. This study includes abrasion loss, permeability, and skid resistance performance tests. Utilizing a one-way ANOVA, results were examined. The findings indicate that there is no statistically significant relationship between age and skid resistance or abrasion loss. Meanwhile, the resilient modulus and skin temperature differential are statistically significantly impacted by the length of ageing. The combination thoroughly waterproofs the pavement and shows improved resistance to rutting due to its impermeable pavement.

دراسة أداء العجينة الإسفلتية ذات الفجوات المعرضة للتقادم

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الكلمات المفتاحية:
التجريد
التشوه الدائم
التقادم
فقدان التآكل
مقاومة الانزلاق

الملخص

أحد العناصر المهمة في البنية التحتية التي صممها المهندسون المدنيون هي الطرق. العجينة الإسفلتية ذات الفجوات (SMA) هي عبارة عن مزيج أسفلتي تم تطويره مؤخرًا ويتميز بكمية عالية من الركام الخشن والمواد المالئة والإسفلت، مما يميزه عن الأسفلت الكثيف العادي. تمت إضافة 6٪ كربونات الكالسيوم و 2٪ أسمنت بورتلاند عادي إلى المزيج الخشن كمواد مالئة، لمنع التجريد وتقليل تصريف المادة الرابطة إلى الأسفل. يساهم الهيكل الركام عالي الخشونة في إنشاء مصفوفة مستقرة، مما يحسن مقاومتها للتشوه الدائم. الهدف الأساسي لهذه الدراسة هو النظر في مدى تأثير أوقات التقادم ودرجات الحرارة المتنوعة على أداء خلطات SMA. تتضمن هذه الدراسة اختبارات أداء فقدان التآكل والنفاذية ومقاومة الانزلاق. باستخدام ANOVA في اتجاه واحد، تم فحص النتائج. تشير النتائج إلى عدم وجود علاقة ذات دلالة إحصائية بين العمر ومقاومة الانزلاق أو فقدان التآكل. وفي الوقت نفسه، يتأثر معامل المرونة والفرق في درجة حرارة الجلد بشكل كبير إحصائيًا بطول فترة التقادم. يعمل هذا المزيج على مقاومة الرصف تمامًا للماء ويظهر مقاومة محسنة للتخدد بسبب رصفه غير المنفذ.

1. Introduction

One crucial element of the infrastructure designed by civil engineers is the highway. Rutting is one among the greatest prevalent pavement distresses, and it might be partially attributed to large vehicles' continuous loading. To ensure that to improve mix resistance to rutting, a new mix type called Stone Mastic Asphalt (SMA) is introduced. Numerous studies have been conducted on Asphalt

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mixture behavior-influencing factors. Nonetheless, bituminous blends exhibit extremely complex behavior in the presence of traffic and environmental factors. Asphalt mixtures must possess the ability to resistant to permanent deformation, resistant to cracking, and resistant to moisture damage to function successfully in a pavement system [1]. As mentioned in the review, the aggregate's gradation acts as the mixture's mineral structure, has a significant influence on the mechanical properties of asphalt mixture and that the presence of granular gaps increases the mixture's compatibility [2]. According to Hadiwardoyo et al. (2013), in typical highway circumstances, the greater the speed, the lower the skid resistance of a particular surface, which is a function of the actual speed [3]. The force produced when a non-turning wheel slides on pavement, it has shown to be crucial for raising traffic safety and preventing potential mishaps [4]. Qian, G., et al. (2024) state that the microtexture and macrotexture present on pavement surfaces determine the resistance to skidding [5]. An increase in temperature causes the asphalt to become softer and less sticky, creating a smoother surface and lessening the mixture's resistance to Skidding [6]. The Cantabro test, according to Hamzah et al. (2012), is employed to evaluate the mix's resilience against impact and abrasion pressures. Based on the study's findings, mixes' drainage capacity rises as the air void percentage increases, this results in a decrease in resistance to abrasion loss [7]. Modifiers have the ability to significantly reduce the abrasion loss of open-grade mixtures [8]. The Cantabro loss of porous asphalt specimens was found to be significantly influenced by specimen initial conditioning and ambient temperature [9]. According to Suresha et al. (2009), a decrease in average unaged wear loss was observed with an increase in compressive stress and binder content. The engineering qualities and functionality of the SMA mixture are assessed in this work. .

2. Materials

2.1 Asphalt Binder

The Shell Bitumen Company's 60/70 asphalt binder was used as base binder, and the characteristics are listed in Table (1) [10].

Table 1: Properties of Base Binder [10].

Ageing Condition	Property	Values
Un-aged	Penetration	63
	Softening Point (ºC)	48
	Ductility at 25ºC (cm)	115
	Relative Density at 25ºC	1.03
	G*/sinδ at 64ºC (Pa)	1621.40
Short-Term Aged	G*/sinδ at 64ºC (Pa)	3584.20
Long-Term Aged	G* sinδ at 25ºC (MPa)	4.51

2.2 Coarse and Fine Aggregates

The geometrically cubical aggregate (GCA) of crushed granite was obtained from Kuad Quarry Sdn. Bhd., Penang. Figure (1) and Table (2) display the aggregate's fundamental characteristics as well as the gradation that was employed [11].

Table 2: Engineering Properties of GCA [11].

Property	Test result	Test method
Bulk Specific Gravity (g/cm3)	2.624	AASHTO T85
Absorption (%)	0.53	AASHTO T85
Polished Stone Values	51.10	ASTM D3319
Flat and Elongated (%)	13.56	BS 812
Los Angeles Abrasion (%)	8.0	ASTM C131
Aggregate Crushing Value (%)	16.77	BS 812-110

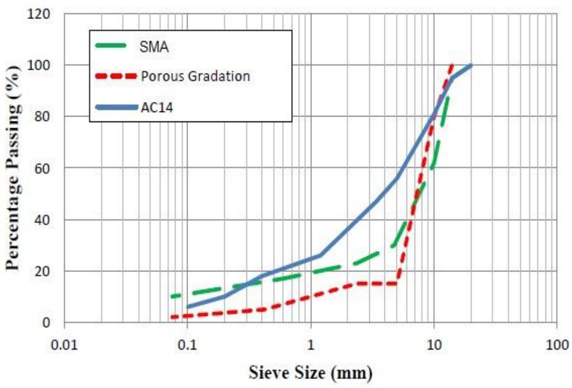

Fig 1: Aggregates Gradation of SMA [11]

2.3 Filler

As filler, 6% $CaCO_3$ with 2% OPC was used. Table (3) displays the results of the determination of the fillers' specific gravity using AASHTO T 133.

Table 3: Specific Gravity of Fillers

Filler Type	Result (g/cm^3)
$CaCO_3$	2.85
OPC	3.14

3. Methodology of Study

3.1 Asphalt Mixture Preparation

The mixes were compacted with a Marshall hammer. An inner diameter of 101.6 mm was the standard Marshall mould that was used to prepare the GGA at 5.9% optimal binder content using fillers.

Following AASHTO R30 [12], the trays were mixed and then put into a draft oven set at 135°C for tow and six hours. The mixes were compacted, allowed to cool to room temperature, and then extruded after four hours.

3.2 Resilient Modulus Test

Using the Universal Asphalt Testing Machine displayed in Figure (2), the resilient modulus test was conducted in the indirect tension loading mode. For four hours, the specimens were stored in a temperature cabinet at 25 °C. Then the specimen's measurements were taken and entered prior to the test. Approximately 10 percent of the ITS compressive load was applied vertically on the vertical diameter plane of the specimen. The electronic measurement system was changed as needed. During the test, the specimen was rotated by around 90° to find its modulus average. This test was performed using the parameters listed in Table (4) and was based on ASTM D4123 (ASTM, 2005) procedures [13].

Fig 2: Universal Asphalt Testing Machine

Table 4: Properties of Base Binder

Parameters	Value
Test Temperature	25ºC
Pulse Form	Haversine
Pulse Width (ms)	100
Test Pulse Period	3000
Initial Pulse	5
Final Pulse	5
Compressive Load (N)	1000
Poison Ratio	0.35

3.3 Permeability

The permeability of the materials was ascertained using the air permeameter. The differential pressure theory in the manometer served as the foundation for the construction of this device. It is essential to stabilize the water flow pressure from the water container. The time it took for 50 milliliters of stabilized water to flow out of the container and the difference pressure at the manometer were noted. Equation 1 was employed to determine the coefficient of permeability, k, by acquiring additional values.

$$k = uVL/((A.dP.dt)) \quad (1)$$

Where:

A = Cross Sectional Area of the Sample (cm^2)

k = Permeability (cm^2)

u = Viscosity of air (Poise)

V = Volume of Air Passing (cm^3)

dP = Differential Pressure (dynes per cm^2)

dt = Time taken for Fluid to Pass Through (second)

3.4 Cantabro Test

The resistance of the mixes to ravelling was ascertained using the Cantabro test. The test was conducted using the Los Angeles abrasion drum, and steel balls were not used. To ensure a consistent temperature before the test, the material was conditioned for at least 4 hours at 25 °C. An infrared thermometer was used to measure the temperature of the specimen skin and the interior drum walls before and after the test, then the temperatures were recorded. The difference between the sample's two surface temperatures was designated as the sample temperature change (STC). The definition of drum temperature change (DTC) was the variation in LA drums' inner walls' temperatures. The gearbox was turned 300 revolutions per minute at 30 to 33 RPM. Abrasion and impact pressures were applied to the specimen while the drum rotated. Equation 2, expresses the abrasion loss results as a percentage loss in mass.

$$AL = (Mi - Mf)/(Mi) \quad (2)$$

Where:

AL = Abrasion Loss (%)

Mi = Initial Mass of Specimen (g)

Mf = Final Mass of Specimen

3.5 Skid Resistance Test

The specimens' surface friction was quantified in terms of skid number using skid resistance. The test was conducted using a British portable pendulum slip tester as shown in Figure (3). The temperature of the sample was observed before testing, and to reduce the friction between the rubber roller and the sample's face, water was sprayed over it. This replicates the worst weather conditions, when skidding is common. The tester was positioned and aligned to make sure the rubber slider was gliding across the specimens' surface. After the rubber slider was let go and moved across the specimen's surface, the skid numbers were noted.

Fig 3: Skid Resistance Test

4. Results and Discussion

4.1 Impact of Ageing Duration on Resilient Modulus

The average abrasion loss of mixtures exposed to two ageing durations is displayed in Figure (4).

Mixtures aged for two hours have 1.5% less abrasion loss than those aged for six hours. This outcome demonstrates that the stiffer the binder, the longer the ageing period, increasing the abrasion loss and brittleness of the mixtures. Table (5) contains a tabulation of statistical analysis results. Since the p-value for these blends is greater than 0.05, it may be concluded there is no statistically significant relationship between the amount of abrasion loss and the ageing duration.

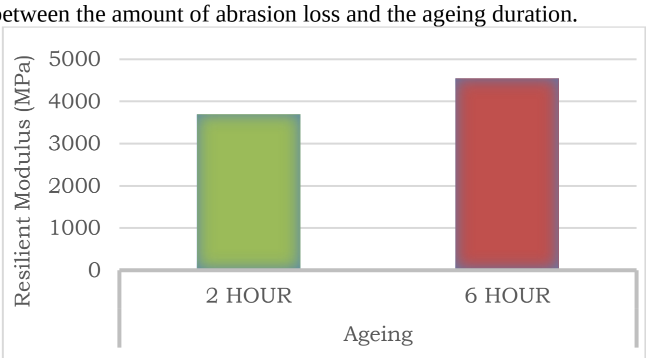

Fig 4: Resilient Modulus versus Aging Duration

Table 5: One-Way ANOVA Results on Resilient Modulus

	SUM of Squares	df	Mean Square	F	Sig
Between Groups	2019402.14	1	2019402.10	18.3	.001
Within Groups	1322684.20	12	110223.70		
Total	3342086.30	13			

4.2 Effect of Aging Duration on Abrasion Loss

As shown in figure (5), before and after the test, temperatures were noted in the specimen's surface and in the drum. Three hundred revolutions caused a considerable difference in temperature. Friction between the sample's surface and the drum's inside caused heat to be produced. Table (6) contains a statistical analysis results. Given that the STC p-value is less than 0.05, it's clear, that the ageing time has a significant impact on STC. Nonetheless, the p-value for DTC is more than 0.05, indicating that there is no significant effect between ageing and DTC.

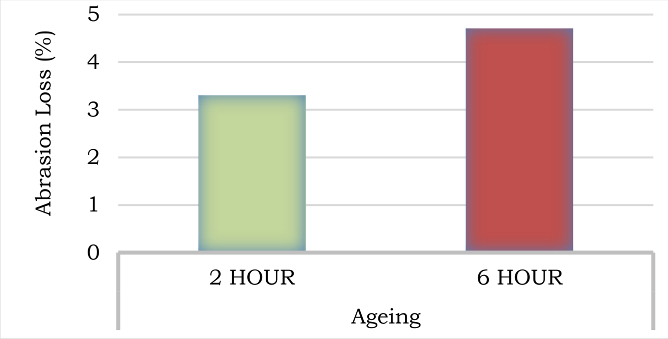

Fig 5: Abrasion Loss versus Aging Durations

Table 6: Statistical Analysis Results of Abrasion Loss

	SUM of Squares	df	Mean Square	F	Sig
Between Groups	2.37	1	2.37	1.38	.361
Within Groups	3.43	2	1,71		
Total	5.80	3			

4.3 Drum and Sample Skin Temperature Changes

The average abrasion loss of mixtures exposed to two ageing durations is displayed in Figure (6). Mixtures aged for two hours have 1.5% less abrasion loss than those aged for six hours. This outcome demonstrates that the stiffer the binder, the longer the ageing period, increasing the abrasion loss and brittleness of the mixtures. Table (7) contains a tabulation of statistical analysis results. Since the p-value for these blends is greater than 0.05, it may be concluded there is no statistically significant relationship between the amount of abrasion loss and the ageing duration.

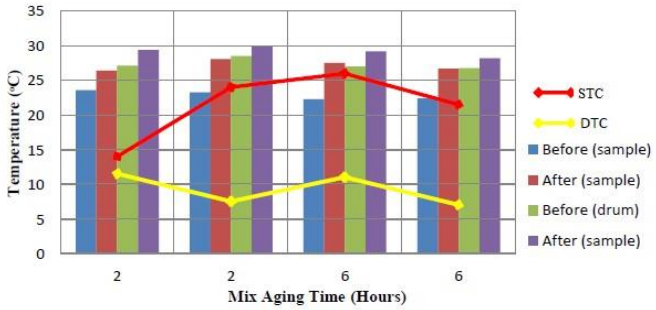

Fig 6: Temperature of STC, DTC Before and After Testing at 25°C

Table 7: Statistical Analysis Results of STC and DTC

		Sum of Squares	df	Mean Square	F	Sig
DTC	Between Groups	.050	1	.05	.14	.714
	Within Groups	6.50	18	.36		
	Total	6.55	19			
STC	Between Groups	4.51	1	4.51	6.14	.023
	Within Groups	13.23	18	.735	13.23	18
	Total	17.74	19			

4.4 Effect of Aging Duration on Skid Resistance

Figure (7) displays the resistance of skid outcomes of mixes that were aged for varying periods of time. Mixtures matured for six hours have a higher level of skid resistance than mixes aged for two hours. Similar results are shown by the mean skid number for both ageing durations. Table (8) contains a statistical analysis results. The test's p-value is greater than 0.05, concluded there is no statistically significant relationship between the amount of abrasion loss and the ageing duration.

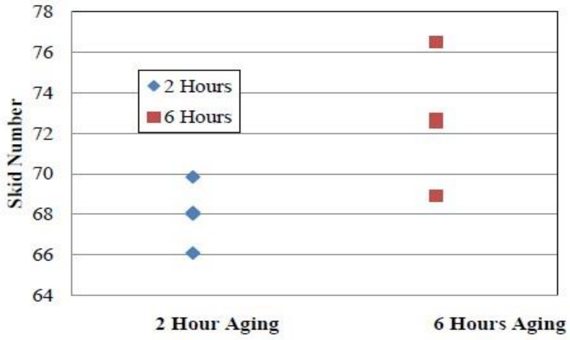

Fig 7: Skid Number for Different Aging Duration

Table 8: Statistical Analysis Results of Skid Resistance

	SUM of Squares	df	Mean Square	F	Sig
Between Groups	.000	1	.00	.00	1.00
Within Groups	828.00	94			
Total	828.00	95			

4.5 Effect of Permeability on Aging Duration

The water in the container did not leak during the permeability test. Air cannot enter through the asphalt specimen, indicating the specimen has an extremely low coefficient of permeability. The water permeability test using air pumping produced similar results.

5. Conclusion

The study examined the effects of mixture ageing duration on the performance of engineering. Considering the results of the laboratory, the following deductions can be made:

1. The statistical analysis programme SPSS 20 examine the engineering characteristics of Stone Mastic Asphalt (SMA) in terms of performance. Resilient modulus is significantly impacted by the ageing conditions. Specimens aged for six hours have a robust modulus that is 20% greater than those aged for two hours.
2. Ageing does not statistically significantly affect abrasion loss. Specimens aged for two and six hours had abrasion losses of about 3.2% and 4.7%, respectively.
3. The ageing has no statistically significant effect on skid resistance.
4. The SMA coefficient of permeability is extremely low, based on the findings of the permeability test. The mix's air void continuity is disrupted by the high bitumen and filler component.

The following recommendations are assessed,

- To evaluate the impact of mix performance, samples with different aggregate shapes can be used.
- The warm-mix asphalt additives can be used.

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