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ORIGINAL ARTICLE

The Influence of Eggshell Powder as Additive on the Physical and Mechanical Properties of Stone Mastic Asphalt

H. C. Goh[1*], P.J. Ramadhansyah[1,2]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Malaysia.
[2]Institute for Infrastructure Engineering and Sustainability Management, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

ABSTRACT – Stone mastic asphalt (SMA) has been widely used in Europe since the early 1960s, followed by numberous trials in countries such as the USA and Australia, where it has been positioned as a premium pavement surfacing course purposely for heavy duty pavements, highways and other roads with heavy truck traffic. In addition, Malaysia's demand for 900 million eggs per month produces a significant amount of solid waste. If all these eggshells were recycled and used for fertiliser or other purposes, this would help to reduce the overall amount of solid waste to a certain level. The eggshell in the solid food waste has been studied in detail and found to be suitable for processing into eggshell powder (EP) additives and applied to today's construction industry. Thus, this research learnt the influence of EP as bitumen modification in stone mastic asphalt (SMA) in term of physical and mechanical properties. Moreover, this research also determines the optimum percentage of EP as the bitumen modifier by the combination of 0%, 4%, 8% and 12%. The physical properties of SMA can determine through cantabro loss, permeability and marshall stability test, while the mechanical properties of SMA can determine through indirect tensile strength. In short, 12% of ESP was the optimum percentage as bitumen modifier in SMA, it increased the strength in the mechanical properties from 201 kPa to 230 kPa.

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INTRODUCTION

Designers Stone mastic asphalt (SMA) mixtures were produced in Germany to withstand high loads from heavy traffic and nailed tyres while maintaining a strong macrotexture [1]. According to [2], the strong skeleton used and high interlock among coarse aggregates made SMA mixtures achieved remarkable rutting performance, followed by the strong mastic asphalt, filler, and stabilizing additives that filled the voids between coarse aggregates.

The replacement of construction materials with waste materials can reduce the construction material cost and contribute to the environment. In addition, additive made up of waste material can positively increase the characteristic required for a construction purpose [1, 3-6]. Nowadays, solid wastes such as coconut shells, oil palm shells, rice husk, tyre rubber crumb, fly ash and bottom ash can be used in the construction industry to maximize profit while reducing the amount of waste [7-13]. The construction industries are searching for alternative products that can reduce construction costs.

[14] stated that the demand for eggs per month is 900 million eggs in Malaysia. There was a need for the food processing industry to find alternative methods for processing and using eggshells in a way that is beneficial to the environment. According to [4], eggshells were known to have high calcium carbonate ($CaCO_3$) which similar to limestone, one of the primary materials of cement. Most of the time, eggshell waste was commonly disposed of in landfills since it is traditionally considered useless.

In the other hand, this research focus on the investigation of the optimum percentage of the eggshell powder (EP) as bitumen modifier and the performance of the SMA with EP as additive. The importance of this research is the performance or characteristic improvement of bitumen and SMA since flexible pavement was the most widely used in Malaysia. Besides, it resolved to arise environmental issues such as waste disposal problems that mainly caused environmental pollution and public health crisis.

EXPERIMENTAL PROGRAMME

Material Preparation

EP was produced through self-collect eggshell waste. Firstly, the eggshell waste was collected from caterers. Then, the eggshell waste was washed by using tap water. Next, the cleaned eggshell waste is dried in the oven with temperature 105°C for 24 hours [6, 12]. After that, the dried eggshell waste was then crushed and ground in the grinding machine into powder form, followed with sieved and passed 150µm sieve. Apart from that, the cleaned eggshell waste also can be burned in furnace at 800˚C for 2 hours, this is to achieve optimum mix's purpose [12]. The EP that passed 150µm sieve was collected and sealed in a clean container.

*CORRESPONDING AUTHOR | H. C. Goh | ✉ gohhongchee@gmail.com

The 60/70 penetration grade bitumen was used for this research. The optimum binder content to use has been adopted by previous study [15]. The Modified Bitumen Apparatus was used to modify the bitumen with the additive of EP. The percentage of EP was modified by the weight of the bitumen. The aggregates were sieved by using Vibrator Sieve Shaker and properly packaged according to its sizing. The 'Orang Kuat' Ordinary Portland Cement (OPC) of grade 52.5N was used in this research. The aggregate gradation of SMA 20 used in this research was conformed to [16]. The Table 1 showed the Chemical Composition of EP and selected aggregate gradation of SMA 20 used in this research.

Table 1. Chemical Composition of EP [6].

Element	ESP (%)
Calcium Oxide (CaO)	52.10
Magnesium Oxide (MgO)	0.06
Silica Dioxide (SiO_2)	0.58
Alumina (AI_2O_3)	0.06
Ferric Oxide (Fe_2O_3)	0.02
Chloride (Cl)	-
Sulphur Trioxide (SO_3)	0.62
Potassium Oxide (K_2O)	0.25
Sodium Oxide (Na_2O)	0.15
Loss on Ignition (LOI)	45.42

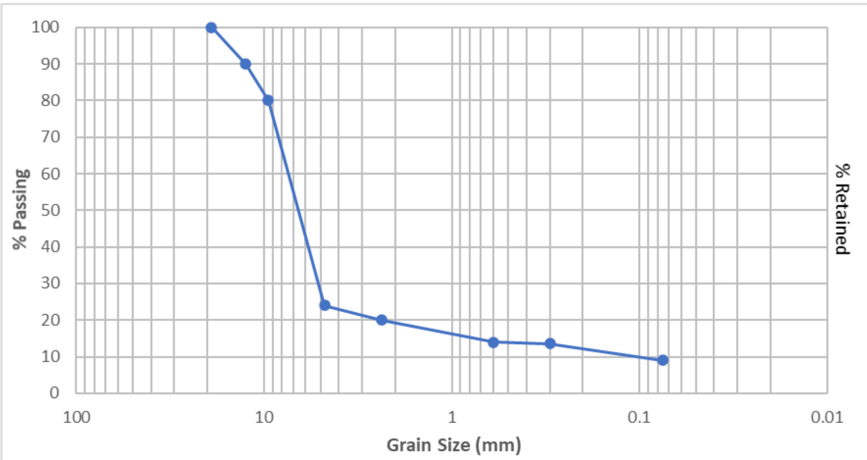

Figure 1. Aggregare Gradation of SMA20.

Aggregate Properties

Table 2 showed the aggregate properties results. The recommended Aggregate Impact Value for aggregate should be between 20% and 30% [16]. The As shown in Table 2, the Aggregate Impact Value of aggregate is 22.10% which fulfil the requirement (between 20% and 30%) of Malaysian Standard Specification for Road Works. The recommended Aggregate Crushing Value for aggregate should be less than 25% [16]. The Aggregate Crushing Value of aggregate is 9.38% also meet the requirement (less than 25%) of Malaysian Standard Specification for Road Works.

Table 2. Physical Properties of Aggregate.

Properties	Results	Specification	Status
Aggregate Impact Value (AIV)	22.1%	20% - 30%	Pass
Aggregate Crushing Value (ACV)	9.38%	< 25%	Pass

Bitumen Properties

The percentage of EP was modified by the weight of the bitumen. Based on the Table 3, the unmodified bitumen and modified bitumen with 4%, 8% and 12% EP were meet the Softening Point requirement of JKR Specification for bitumen penetration grade 60/70, all Softening Point results of the modified bitumen were obtained in the range of 49 °C to 56 °C.

On the other hand, the unmodified bitumen only fulfil the requirement Penetration requirement of JKR Specification for bitumen penetration grade 60/70, which was in the range of 60 mm to 70 mm. The modified bitumen with 4%, 8% and 12% EP were not fulfil the requirement Penetration requirement of JKR Specification for bitumen penetration grade 60/70, all Penetration results of the modified bitumen were less than 60 mm. This may be due to the chemical reaction of the EP with the bitumen components, which made the connections between the bitumen molecules in the modified bitumen stronger than in the unmodified bitumen [17].

Table 3. Softening Point Results.

EP	Results	Specification	Status
0%	54.6 °C	49 °C - 56 °C	Pass
4%	53.4 °C	49 °C - 56 °C	Pass
8%	53.7 °C	49 °C - 56 °C	Pass
12%	53.9 °C	49 °C - 56 °C	Pass

Table 4. Penetration Results.

EP	Results	Specification	Status
0%	65.5 mm	60 mm - 70 mm	Pass
4%	28.33 mm	60 mm - 70 mm	Fail
8%	30.33 mm	60 mm - 70 mm	Fail
12%	27.67 mm	60 mm - 70 mm	Fail

Cantabro Loss Test

The objective of the Cantabro Loss Test was to determine the ravelling resistance of specimens using Los Angeles Abrasion Machine. The procedure was specified at ASTM D 7064-08. The initial weight of the specimen before revolution was recorded. Next, the weights are obtained every 100 revolutions up to 300 revolutions for each sample. Equation 1, where L represents the percentage of mass loss, M_{before} represents the mass of specimen before revolution (g) and M_{after} represents the mass of specimen after revolution (g). represents the mass of specimen before revolution (g).

$$L = \frac{[M_{after} - M_{before}]}{[M_{before}]} \times 100\% \qquad (1)$$

Permeability Test

The Permeability Test was used to determine the permeability coefficient of the specimens. The procedure was specified at ASTM D 5084-03. The permeability coefficient can be calculated using Equation 2, where k represents permeability coefficient, a represents cross-sectional area of the standpipe (cm^2), l represents the thickness or height of the specimen (cm), A represents cross-sectional area of the specimen (cm^2), h_1 represents the heads at the beginning (cm), h_2 represents the end of the measurement (cm), and t represents the time taken for water in the standpipe to fall from h_1 to h_2 (s).

$$k = \frac{al}{At} \ln\left(\frac{h_1}{h_2}\right) \qquad (2)$$

Marshall Stability Test

Marshall Stability and Flow Test was used to measure the resistance to plastic flow of cylindrical specimens of an asphalt paving mixture loaded on the lateral surface by means of the Marshall Apparatus. The procedure was specified at ASTM D1559. However, Density and Void Analysis was used to prepare standard asphalt concrete for the determination of stability and flow in the Marshall apparatus and to determine density, percentage air voids and percentage of aggregate voids filled with binder. The procedure was specified at ASTM D 2726.

Indirect Tensile Strength (ITS)

ITS was used to evaluate the relative quality of asphalt mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The procedure was specified at ASTM D 6931. The ITS can be calculated using Equation 3, where ITS represents Indirect Tensile Strength (kPa), P represents maximum load (kN), t represents specimen thickness and D (m) represents specimen diameter (m).

$$ITS = \frac{2P}{\pi t D} \qquad (3)$$

RESULTS AND DISCUSSIONS

Cantabro Loss

As shown in Figure 2, the modified bitumen with 12% EP in SMA showed slightly higher the Cantabro Loss value than other three samples after 300 revolutions, while the modified bitumen with 4% EP in SMA showed the least Cantabro

Loss value after 300 revolutions. From the graph below, we can conclude that a small amount of eggshell powder helps to increase the resistance of SMA to Cantabro Loss, thereby enhancing the performance of the SMA. Furthermore, the average mass loss is less than 15%, which is acceptable according to the JKR specification.

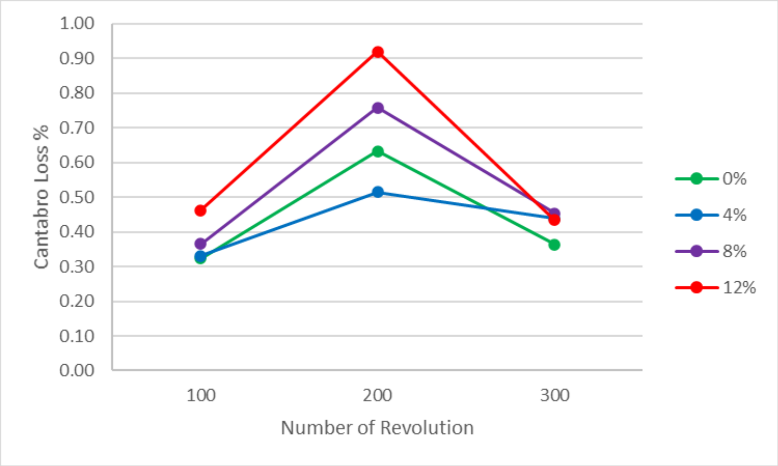

Figure 2. Cantabro Loss % vs Number of Revolution.

Permeability

As shown in Figure 3, the highest Permeability Coefficient among the samples is the unmodified bitumen with 0% EP in SMA with 11.885 cm/s and the lowest Permeability Coefficient among the samples is the modified bitumen with 12% EP in SMA with 5.565 cm/s. In addition, the Figure 3 clearly showed that the Permeability Coefficient decreases with the increasing EP.

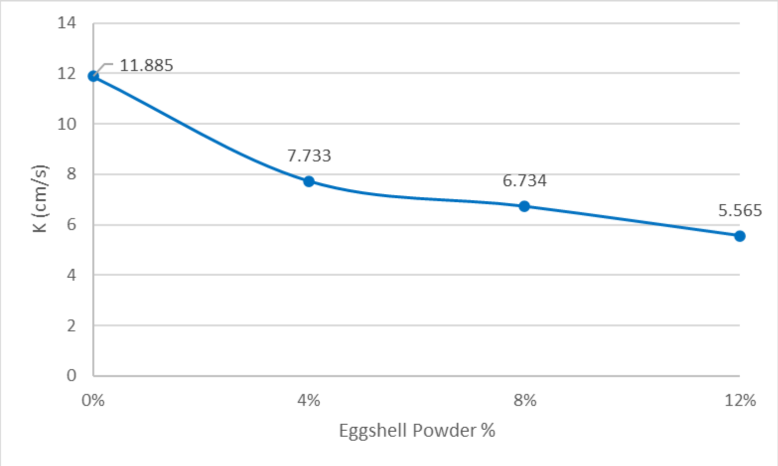

Figure 3. Permeability Coefficient of different EP %.

Stability and Bulk Density

As shown in Figure 4, the highest Stability among the samples is the unmodified bitumen with 0% EP in SMA with 4.829 kN and the lowest Stability among the samples is the modified bitumen with 4% EP in SMA with 1.674 kN, while the highest Bulk Density among the samples is the unmodified bitumen with 0% EP in SMA with 2.103 g/cm^3 and the lowest Bulk Density among the samples is the modified bitumen with 4% and 8% EP in SMA with 2.063 g/cm^3. Besides, the Figure 4 clearly showed that the Stability decreased with the increasing EP and the Bulk Density slight increased with the increasing EP.

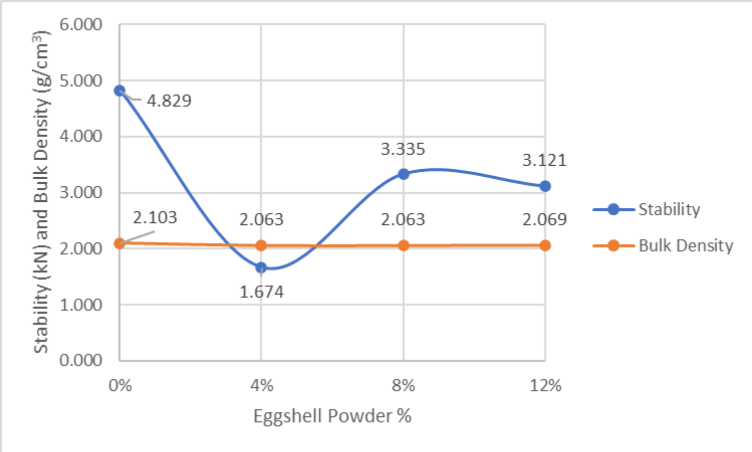

Figure 4. Relation between Stability and Bulk Density of SMA with different EP %.

Stability and Flow

As shown in Figure 5, the highest Flow among the samples is the modified bitumen with 8% EP in SMA with 10.665 mm and the lowest Flow among the samples is the unmodified bitumen with 0% EP in SMA with 4.664 mm. Furthermore, the Figure 5 clearly showed that the Stability decreased with the increasing EP and the Flow increased then decreased with the increasing EP.

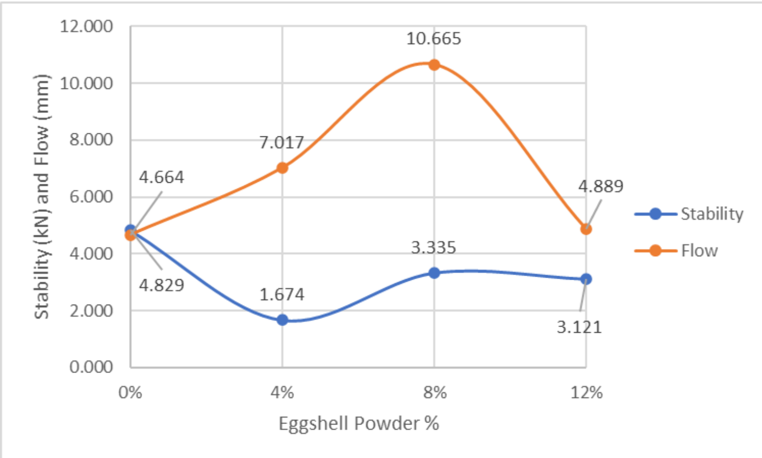

Figure 5. Relation between Stability and Flow of SMA with different EP %.

Stiffness

As shown in Figure 6, the highest Stiffness among the samples is the unmodified bitumen with 0% EP in SMA with 1.068 kN/mm and the lowest Stiffness among the samples is the unmodified bitumen with 0% EP in SMA with 0.237 kN/mm. On the other hand, the Figure 6 clearly showed that the Stiffness increases with the increasing EP.

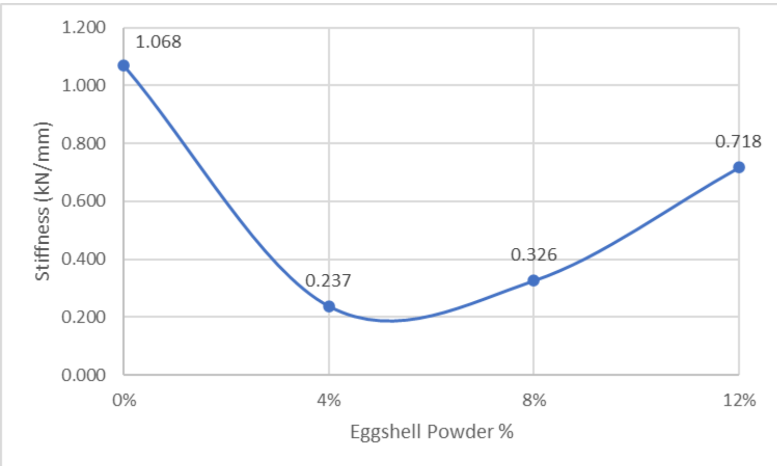

Figure 6. Stiffness of SMA with different EP %.

Voids in Total Mix (VTM)

As shown in Figure 7, the lowest VTM among the samples is the unmodified bitumen with 0% EP in SMA with 14.30% and the highest VTM among the samples are the modified bitumen with 4% and 8% EP in SMA with 15.94%. Moreover, the Figure 7 clearly showed that the VTM trend slightly decreases with the increasing EP.

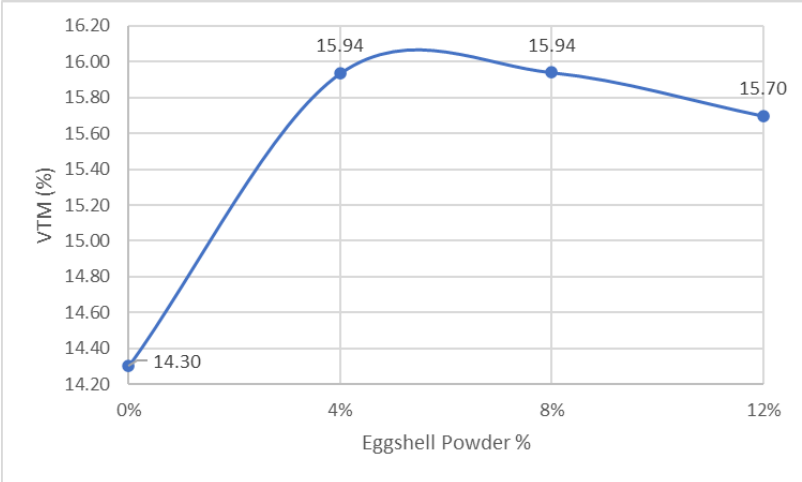

Figure 7. VTM of SMA with different EP %.

Voids in the Mineral Aggregate (VMA)

As shown in Figure 8, the lowest VMA among the samples is the unmodified bitumen with 0% EP in SMA with 26.69% and the highest VMA among the samples is the modified bitumen with 8% EP in SMA with 28.10%. Moreover, the Figure 8 clearly showed that the VMA trend slightly decreases with the increasing EP.

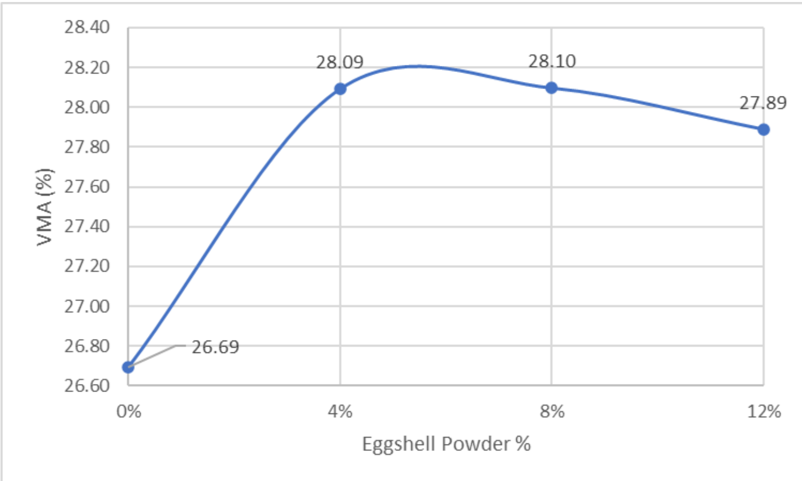

Figure 8. VMA of SMA with different EP %.

Void Filled with Asphalt (VFA)

As shown in Figure 9, the highest VFA among the samples is the unmodified bitumen with 0% EP in SMA with 53.60% and the lowest VFA among the samples is the modified bitumen with 4% EP in SMA with 49.91%. Additionally, the Figure 9 clearly showed that the VFA slightly increases with the increasing EP.

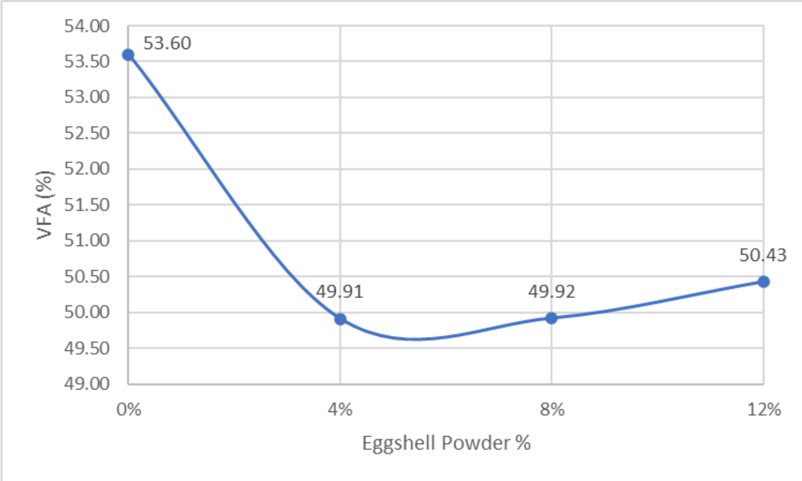

Figure 9. VFA of SMA with different EP %.

Table 5. Marshall Test Results.

EP	Binder %	Spec. Height (mm)	Weight in (g)			Bulk Vol. (cc)	Specific Gravity	
			Air	Water	SSD		Bulk Den.	Max Theoretical
0%	7	77.33	1135.65	613.45	1153.50	540.05	2.103	2.454
4%	7	74.63	1146.00	607.85	1163.40	555.55	2.063	2.454
8%	7	74.96	1193.15	627.10	1205.60	578.50	2.063	2.454
12%	7	72.98	1162.50	611.55	1173.55	562.00	2.069	2.454

EP	Volume-% Total			Voids (%)		
	Bit.	Agg.	Voids	VMA	VFA	VIM or Va
0%	14.292	73.305	12.402	26.695	53.601	14.303
4%	14.020	71.907	14.073	28.093	49.908	15.937
8%	14.019	71.904	14.077	28.096	49.918	15.941
12%	14.060	72.112	13.828	27.888	50.428	15.698

EP	Stability Corr. Ratio	Stability (kN)		Flow (mm)	Stiffness (kN/mm)
		Div.	Corr.		
0%	0.930	5.193	4.829	4.664	1.068
4%	0.875	1.905	1.674	7.017	0.237
8%	0.835	4.066	3.335	10.665	0.326
12%	0.860	3.639	3.121	4.889	0.718

Table 6. Values of the characteristics of the SMA with different EP %.

EP	Bulk Density (g/cm^3)	Stability (kN)	Flow (mm)	Stiffness (kN/mm)	VTM (%)	VMA (%)	VFA (%)
0%	2.103	4.829	4.664	1.068	14.30	26.60	53.60
4%	2.063	1.674	7.017	0.237	15.94	28.09	49.91
8%	2.063	3.335	10.665	0.326	15.94	28.10	49.92
12%	2.069	3.121	4.889	0.718	15.70	27.89	50.43

Indirect Tensile Strength (ITS)

As shown in Figure 10, the highest ITS among the samples is the modified bitumen with 12% EP in SMA with 230 kPa and the lowest ITS among the samples is the modified bitumen with 4% EP in SMA with 124 kPa. Moreover, the Figure 10 clearly showed that the ITS increases with the increasing EP.

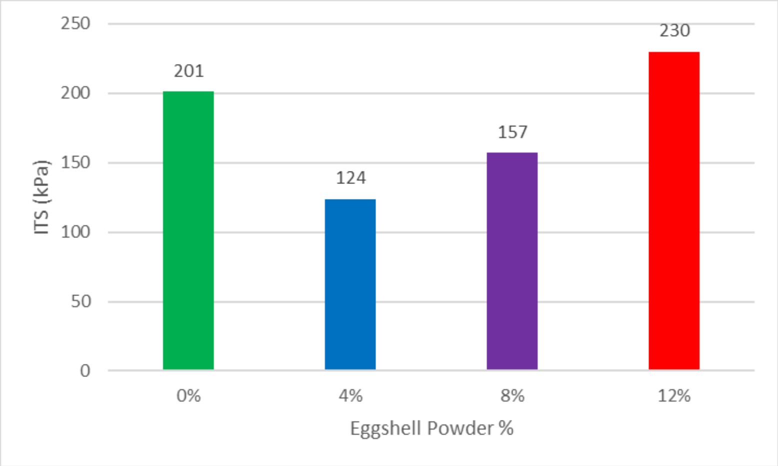

Figure 10. ITS of SMA with different EP %.

CONCLUSION

The physical and mechanical properties of EP as additive in SMA was investigated. It can be observed that the percentage of eggshell used as additive in SMA has a significant effect on the properties of the modified SMA. 4% EP helps to slightly increase the resistance of SMA to Cantabro Loss. Moreover, the Permeability Coefficient decreased with the increasing EP. In addition, the Bulk Density slightly increased with the increasing EP. Furthermore, Marshall properties obtained showed that the Stability decreased with the increasing EP and the Flow decreased with the increasing EP, while the Stiffness increased with the increasing EP. Besides, volumetric properties such as the VTM and the VMA both are slightly decreased with the increasing EP, while the VFA slightly increased with the increasing EP. On the other hand, the ITS increased with the increasing EP. Lastly, the optimum percentage of the EP used as additive in SMA was determined based on the Indirect Tensile Strength, which is 12% EP illustrated the best results compared to other specimens.

The recommendations are the other mechanical properties tests can be performed in the future such as Resilient Modulus Test and Dynamic Creep Test, in order to present more comprehensive mechanical properties and determine the optimal percentage of EP in a more objective manner. Next, the dried eggshells can be pulverized and ground into the powder in a grinder, then sieved and passed through a 50 μm sieve. The smaller the powder size, the larger the surface area of the powder. The larger surface area of EP facilitates optimal mixing. On the other hand, the dried eggshells can also be burned in furnace at 800 ˚C for 2 hours, which helps achieve optimal mixing [12]. Increase the percentage of EP used as additive in SMA from 4 differences percentage to more will help identify a more complete trend.

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