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# Stress and Strain Characteristic of Stone Mastic Asphalt Incorporating Eggshell Powder

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**Abstract.** Stone mastic asphalt (SMA) is a type of gap graded asphalt mixture. Due to large difference between the gap of large and small size aggregate, this type of mixture suffers a few drawbacks such as low resistance towards permanent deformation. Thus, the usage of eco-friendly and sustainable additive is crucial in enhancing the performance of SMA. Thus, this study is utilizing various amount of eggshell powder as asphalt modifier. Among the tests involve to evaluate the stress-strain characteristic of modified SMA are Resilient Modulus Test and Dynamic Creep Test. From the test, it shows that the addition of 4% eggshell powder produces the highest value of resilient modulus and lowest value of dynamic creep for SMA. In conclusion, this study proves that the eggshell powder is capable in enhancing the performance of SMA especially in terms of permanent deformation resistance.

## 1. Introduction

The concept of layered system had been used for this pavement. It consists of a series of layer including the surface of pavement that has excellence quality materials, which is subgrade, sub-base course, base course, binder course and surface course. There is also a prime coat, seal coat and tack coat between base, binder and surface course. The highest coating of pavements should use the greatest materials to bear maximum compressive stress from the vehicles and the lower layers will encounter lesser magnitude of stress and low material can be used. Therefore, the top layer is most important to use a mixture that have self-healing properties due to heavier wheel loads and keep below allowable stress [1]. This pavement also has less flexural strength than rigid pavements. One type of surface layer of flexible pavement is gap graded asphalt. The advantages of this type of asphalt mixture is having high resistance to rutting, improved low temperature performance, improved macro-texture, and reduction of tire noise and also ease of compaction with static rollers. For stone mastic asphalt (SMA) high quality of materials is required. Cubical, low abrasion, crushed stone, and manufactured sand are recommended to use because the mixtures will gain most of its strength when aggregates are all in contact or stone on stone aggregate concept. The aggregates also should have high polish values to retain good skid resistance where stone mastic asphalt is the final surface of the pavements. SMA is produced in an asphalt plant in the same manner as dense graded asphalt.



However, SMA requires in high quality control in both production and laying. Usually asphalt paving equipment is used and a light tack coat is normally applied. Therefore, good quality of material used is essential to produce good performance of SMA mixture. Among the reliable additive to enhance the performance of paving materials are waste materials. These types of materials not only low cost & easy to obtain, but it can significantly increase the sustainability due to the reuse of waste material can decrease the negative impact towards environment. Study by various researchers [2] and [3], the utilization of eggshell powder can significantly increase the performance of cementitious material. Thus, this research study is done to identify the characteristic and the performance of stone mastic asphalt incorporating eggshell powder. This research might provide ways of optimizing the eggshell powder performance in asphalt pavement

## 2. Materials and methods

### 2.1. Materials

For this study, penetration grade 60/70 bitumen was used to prepare SMA20 mixtures. Then, the eggshell used was 0% to 6% with the increment of 2% by weight of mixture. Table 1 and Table 2 show the properties of aggregate and bitumen used in this study. All materials fulfil the requirement stated by Malaysian Public Work Department for Roadworks [4].

**Table 1.** Aggregate Gradation for SMA20

Sieve Size (mm)	Passing (%)	Retained (%)	Retained (G)
19	100	0	0
12.5	85 – 95	10	120
9.5	65 - 75	20	240
4.75	20 – 28	46	552
2.36	16 – 24	4	48
0.6	12-16	6	72
0.3	12-15	0.5	6
0.075	8-10	4.5	54
PAN	0	7	84
OPC	0	2	24
TOTAL			1200

**Table 2.** Physical Properties of Aggregate and Bitumen

Description	Results	Specification	Status
LAAV	21.28%	<25%	Pass
AIV	14.64%	<30%	Strong
ACV	11.96%	<25%	Pass
Penetration	63.33mm	60mm to 70mm	Pass
Softening Point	49°C	48°C to 52°C	Pass

Eggshell Powder used is obtained from Concrete Pharmacy company at Selangor, Malaysia. The size of eggshell powder used was in micro size. Figure 1 shows the eggshell powder while Table 3 shows the chemical properties of eggshell powder.



**Figure 1.** Eggshell Powder

**Table 3.** Chemical Properties of Eggshell Powder

Description	Composition, %
Calcium Oxide	62.35%
Sulphur Trioxide	1.32%
Iron Oxide	0.63%
Silicon Dioxide	0.61%
Magnesium Oxide	0.36%
Potassium Oxide	0.22%
Aluminum Oxide	0.07%

### 2.2. Sample preparation

The bituminous mixture was prepared by using SMA graded aggregates with 60/70 penetration grade bitumen with the eggshell powder. The crush aggregate granites have been dried and sieved into a selected size range with nominal size of aggregates. The dry blending method has been used in this research which the eggshell was added to the mixture before the binder and the optimum binder content for this research was 6.2% by weight of the mix, where this comes from the past research [5]. All specimen was prepared using Marshall Compactor machine to have the identity samples. The number of compactions for each of the samples are 50 blows at the top and the bottom side of the specimen. The temperature used for all specimens were controlled in the range of 160°C to 180°C.

### 2.3. Resilient modulus

Resilient modulus test is used to evaluate the performance of asphalt mixture under repetitive loads. The resilient modulus test is the test of elastic modulus based on the strain under repeated load which the load is refer to traffic loading. This test was performed in accordance to ASTM D7369-11 [6]. The sample is placed and haversine load is applied at the side of the specimen with 1000, 2000 and 3000 pulse repetition. Each pulse repetition representing the number of traffic passing through the pavement. The specimens were tested in two test temperatures which were 25°C and 40°C. Figure 2 shows the universal testing machine that is use to perform the resilient modulus test.



**Figure 2.** Universal Testing Machine

#### 2.4. Dynamic creep

Dynamic creep test was performed using Universal Testing Machine (UTM) as well. It is the most commonly used device to measure the permanent deformation of asphalt mixture in laboratory (ASTM E139) [7]. Specimen will be placed in the controlled temperature cabinet for 15 minutes to ensure that equilibrium temperature is reached. Specimen was then placed between the platens. The assembled platens and specimen were aligned concentrically with the loading axis of the testing machine. The displacement measuring device is then attached to the platens. The vertical deformation is then measured by the linear variable differential transducers (LVDTs). In this study, the loading parameters consisted of a haversine wave shape and tested in the temperature of 25°C. The specimen was terminated after 3600 load cycles with taken about 2 hours for each sample.

### 3. Results and Discussion

#### 3.1. Resilient modulus

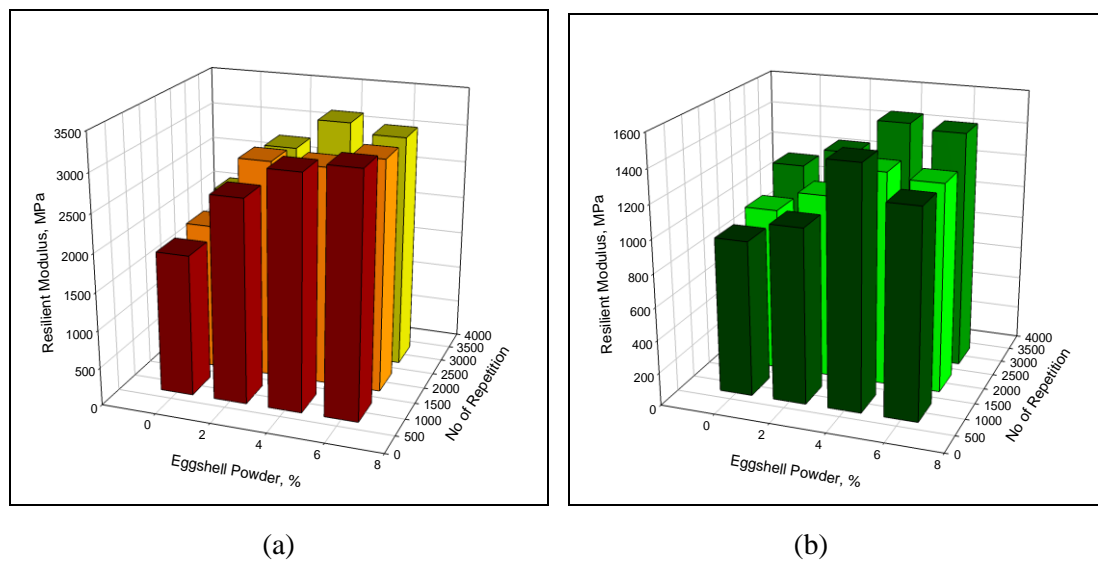
Figure 3 and Figure 4 show the result of resilient modulus for SMA20 with various amount of eggshell powder. The data collection for this test was recorded during the test is shown in Table 4 and Table 5. From the result, it is observed that the resilient modulus for stone mastic asphalt modified sample was higher than unmodified stone mastic asphalt. It indicates the increases of stiffness of samples when eggshell powder is added, which could have greater performance of asphalt pavements to withstand rutting [8]. Based on the results for resilient modulus we can see the result in temperature 25°C is more efficient and higher for modified stone mastic asphalt than test results at temperature 40°C. From Figure 3, the number percentage of eggshell content with highest resilient modulus is 4% at temperature 25°C and 40°C. We can observe that modified sample has higher elasticity modulus at both temperatures. Each figure presents, as the load is applied, the stress increases as does the strain. When the stress is reduced, the strain also reduces but all of the strain is not recovered after the stress is removed [9]

**Table 4.** Average  $M_r$  at 25°C

Eggshell powder content (%)	Average of resilient modulus (Mpa)		
	1000	2000	3000
0	1864	1938	2136
2	2678	2877	2805
4	3070	2876	3207
6	3189	3049	3080

**Table 5.** Average  $M_r$  at 40°C

Eggshell powder content (%)	Average of resilient modulus (Mpa)		
	1000	2000	3000
0	942	998	1156
2	1061	1121	1268
4	1462	1296	1477
6	1258	1264	1445

**Figure 3.** (a) Resilient Modulus 25°C and (b) Resilient Modulus 40°C

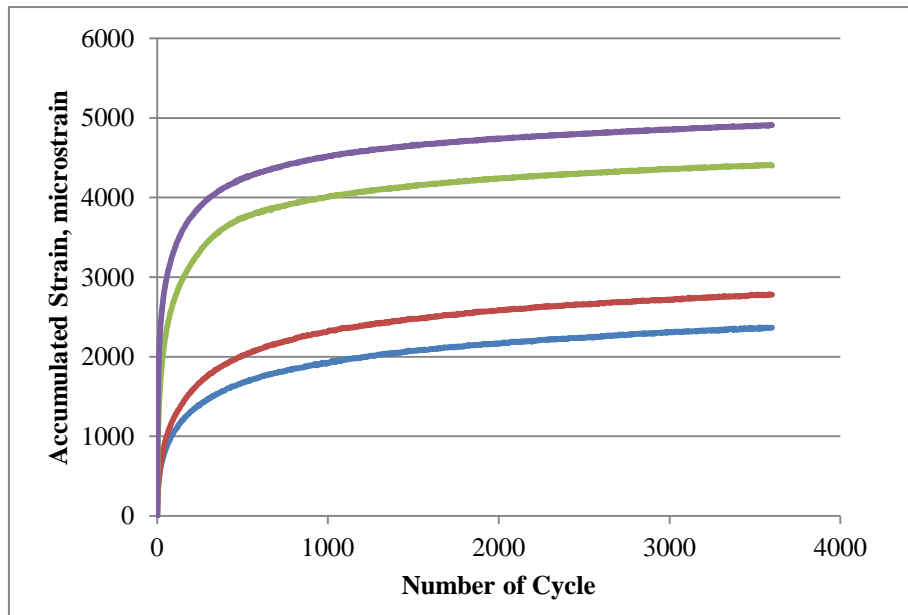
### 3.2. Dynamic creep

After testing, the dynamic creep curves and the value of strain is obtained [10, 12]. Figure 5 presents the comparison of strain value between modified and unmodified sample. From the graph, there is significant different among the curves between the eggshell powder contents. Different eggshell powder content produces different number of strains. From the curve, it shows two stage of the curve which is the primary and secondary stage. In primary stage, it presents the elastic strain of the mixture while secondary stage shows viscoelastic strain by axial stress. There is also tertiary stage but it does not occur for my samples and usually in this stage it shows that the sample has an internal cracking within the material and considered fail. Higher axial strains values indicate that mixes have lower rutting resistance [8] as can be seen in the figure. Results show that the strain for modified sample is better than unmodified stone mastic asphalt mixtures. According to [11], strain for dynamic creep will be reduced if there is modification in term of temperature and bitumen content. The temperature and bitumen content for this research is kept constant. Therefore, the result for dynamic creep is satisfactory. From Table 6, the lowest value of strain is 4% eggshell content with 2366 while the higher value is 0% with 4908 strain respectively.

**Table 6.** Accumulated Strain at 25°C

Eggshell powder content (%)	Strain
0	4908

2	4402
4	2366
6	2799



**Figure 4.** Strain Characteristic of SMA20

#### 4. Conclusion

This study experimentally investigated the strain-stress characteristic of stone mastic asphalt incorporating eggshell powder in terms of resilient modulus and dynamic creep. Based on the results, the following conclusions are drawn: With the addition of eggshell powder in stone mastic asphalt, the average resilient modulus for modified stone mastic asphalt has better result than unmodified samples. For dynamic creep test, it shows that the unmodified stone mastic asphalt has the best result which is because there is no modification on binder content

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