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Evaluation of Stone Mastic Asphalt using Shell Ash as Filler Material

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Abstract: In this study, cockle shell ash was used as a filler material in Stone Mastic Asphalt (SMA) mix to verify the appropriateness and feasibility for the highly traffic roads. SMA is one of the new generations of asphaltic mix and adopted in many countries due to its excellent performance. The main objective of this study is to determine whether the cockle shell as a filler material can improve their performances of Stone Mastic Asphalt on its stability and flow. The manual compaction was carried out to obtain the shell ash and exploited to evaluate the volumetric properties of the design mix. The aggregate gradation of SMA 20 was utilized as the aggregates and 25% increment of cockle shell ash was added as a filler material in this study. The results were compared to conventional or 0% of cockle shell to check the suitability of the materials. The results obtained are adequate and meet the requirement of the standard for SMA Mix.

Key words: Stone mastic asphalt, stability, flow, cockle shell ash

INTRODUCTION

Highways, roadways and roads are one of the most essential modes of transportation system in the world and it plays vital role in economic and social development of the countries. Many roads and highways have been constructed to cater the demands of the people or accomplish the requirements of the community for mobility by providing high quality transport networks which required to be maintained sufficiently. Many nations spent much of their national road budget on maintenance and rehabilitation work of the existing roads apart from upgrading mature road networks and new road infrastructure investments due to the continuous growth in road traffic which has great impact on the pavement structures (OECD/ECMT, 2005).

Increasing the number of vehicles or traffic volume imposes a great amount of stress or strain on the road or highway pavements in the form of traffic loadings and axle loads as the amount of vehicles on the road has increased dramatically over the last few decades due to advances in automotive technology. According to Malaysian Automotive Association (2012), statistics show that the total registered vehicles in Malaysia boosted over last 32 years. The Table 1 shows the passenger cars, commercial vehicles and total vehicles registered in Malaysia from 1980 to 2012.

The pavement structure can bear the loads to some extent, exceeding the limit leads to permanent deterioration of pavements in terms of surface deformation, potholes, edge defects, fatigue cracking, longitudinal cracking, patching, stripping and rutting or plastic flow. These issues can be solved by developing new material types and techniques for the road pavements structures.

Engineers and scientists are frequently investigating various techniques to enhance the performance of the road pavements. Stone Mastic Asphalt (SMA) is one of the methods for the pavement design that is suitable to implement in heavily trafficked roads due to the outstanding performance on pavement structures.

Supplementary materials or additives are being used in pavement materials to enhance the performance and quality of the pavement structure, to provide a durable, impermeable and safe road surface for the road users. Besides, it minimizes the environmental impact of roads in terms of traffic noise, the total expenditure for the repairing and maintenance of the roads structures, exploitation of natural resources etc.

The polymer modified and multi grade bitumen binders offer a long service life for the pavement structure and are able to bear in a high volumetric traffic by preventing permanent deformation known as corrosion, fatigue etc. (Campbell, 1999).

Many studies have been conducted by exploiting different types of waste materials as stabilizing agents or fiber content, filler and aggregate materials in Stone Mastic Asphalt mixture in flexible pavement. Divergent fibers and polymers such as rubbers, polymers, artificial silica, steel slag, ceramic waste, coal fly ash, lime stone, rejected ceramic raw materials, cellulose fiber, synthetic fiber, polypropylene fiber, polyester fibers etc., has been

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Table 1: Summary of new passenger cars and commercial vehicles registered in Malaysia in the year 1980 to 2012

Year	Passenger cars	Commercial vehicles	4x4 vehicles	Total vehicles
1980	80,420	16,842	-	97,262
1985	63,857	26,742	4,400	94,999
1990	106,454	51,420	7,987	165,861
1995	224,991	47,235	13,566	285,792
2000	282,103	33,732	27,338	343,173
2005	416,692	97,820	37,804	552,316
2006	366,738	90,471	33,559	490,768
2007	442,885	44,291	-	487,176
2008	497,459	50,656	-	548,115
2009	486,342	50,563	-	536,905
2010	543,594	61,562	-	605,156
2011	535,113	65,010	-	600,123
2012	552,189	75,564	-	627,753

Source: Malaysian Automotive Association (2012)

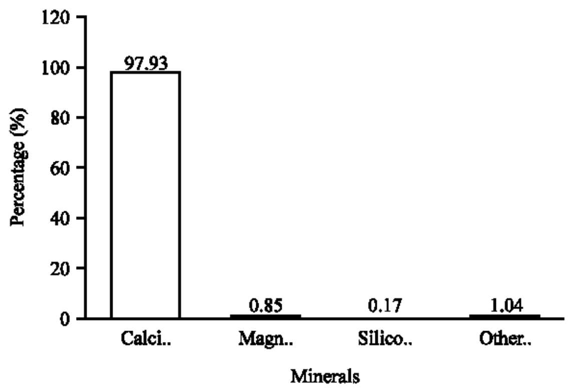

Fig. 1: Mineral Composition of Cockle shells Source: Mohamed *et al.* (2012)

used as stabilizer in Stone Mastic Asphalt mix (Putman and Amirkhanian, 2004). Moreover, some of the mineral fillers in Stone Mastic Asphalt pavements includes rock dust product of various mineralogy, fly ash, Portland cement, Kiln dusts and limestone.

Cockle shells are popular shellfish in heart shaped with two halves of the bivalve joints. The average length of the adult shell is 3-5 inches and mainly used for the purpose of cooking. It contains 12 macro and micro elements known as minerals such as Calcium Carbonate, Sodium, Magnesium, phosphorous etc. The calcium carbonate ($CaCO_3$) comprises 97.93% of total minerals content of the cockle shell and regarded as the highest percentage of mineral present in cockle shell shown in Fig. 1 (Wu *et al*., 2007).

As a result of their high calcium carbonate content, the shell ash can act as cement and bind together with other materials in Stone Mastic Asphalt to enhance the performance of the pavement techniques. In addition, the cockle shell can accomplish the same characteristics of cements by implementing it as a filler material in Stone Mastic Asphalt as both of the materials contains same mineral ($CaCO_3$).

The shells can be used as filler material as it contains high percentage of calcium carbonate which has low abrasion, low oil absorption, high brightness and easy dispersion during mixing process. Besides, it is easy to obtain and also very cheap compare to other materials.

This study was conducted to evaluate the effectiveness of cockle shell as a filler on Stone Mastic Asphalt according to Malaysia Public Works Department specification; Namely JKR specification SMA 20. This study also aims to determine the effects of cockle shell filler on SMA criteria such as stability and flow. The laboratory tests were carried out to determine the properties of the aggregates included sieve analysis and the Marshall Design test were used to samples in accordance with Malaysian Public Work Department specifications.

MATERIALS AND METHODS

Materials

Bitumen: The Polymer Modified Asphalt Performance Grade (PG) 76 or Bitumen Grade 76 is exploited in the preparation of Stone Mastic Asphalt 20 Mix was obtained from Kemaman Bitumen Company (KBC). The amount of bitumen binder content used in this study ranges from 5.5-6.5% for the specimens.

Aggregates: The diverse sizes of gap graded aggregates were obtained from Negeri Roadstone Quarry at Mantin, Negari Sembilan. The aggregate entailed are cleaned, screened crushed hard rock in order to free from dust, clay and unwanted particles such as vegetative, other organic substances and harmful substances. Sieve analysis test catalogues the required aggregate envelope for SMA 20 according to Jabatan Kerja Raya (JKR) /SPJ/2008 specification shown in Table 2.

Cockle shell: Cockle shell or scallops is attained from the market at Traditional Market, Seremban. The fine particles

Table 2: Standard specification for SMA 20 design

	Gradation limit			
Sieve size (mm)	Lower	Upper	Passing (%)	Retained (%)
25	100	100	100	-
19	100	100	100	-
12.5	85	95	90	10
9.5	65	75	70	20
4.75	20	28	24	46
2.36	16	24	20	4
0.6	12	16	14	6
0.3	12	15	13.5	0.5
0.075	8	10	9	4.5

Source: Standard specification for Road Works. Jabatan Kerja Raya (JKR). 2008

of the shell are obtained by manual compaction and the amount of shell ash was blended with mixtures as a percentage of 25, 50, 75 and 100% as filler material in SMA 20 Mix Specimens.

Hydrated lime: Hydrated lime was obtained from commercial source and is in the powder form. Two percent of Hydrated lime was used in the study and it acted as an anti-stripping agent.

Methods: All the trials of SMA 20 mixtures were prepared according to ASTMD 1559/BS 598 and the laboratory works were conducted according to Malaysian Road Works specifications of JKR/SPJ/2008, American Association of State Highway and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM).The specimens were prepared and blended with total amount of 5.5, 6 and 6.5% of bitumen content according to Marshall Mix Design. Three samples were prepared for each percentage of bitumen content with increments of 25% of cockle shell ash for five various mixes at 0, 25, 50, 75 and 100%. Samples were compacted using Marshall Compaction Hammer with 75 blows per face according to the JKR specification.

The Marshall Mix design evaluates the volumetric parameters for the prepared samples of SMA 20. The required amount of raw materials for SMA Mix such as aggregates, filler materials was weighed for the blending purpose. The heating process was carried out by adding the accurate amount of bitumen content to other raw materials at the temperature of 160 -170°C and blends it for 15 min. The prepared samples placed in cylindrical and rectangular moulds for the compaction purpose. The samples were manually compacted 75 times or blow at each faces by Marshall Compaction hammer to meet the requirement for the high traffic design.

RESULTS AND DISCUSSION

Marshall test results: The main objective of Marshall Test is to obtain the parameters of stability and flow, density, percentage of air voids and aggregate voids filled with binder content of the specimens of SMA 20. The Marshall sample preparations and Marshall test was carried out according to ASTM D 1559 for Marshall stability and flow test and ASTM D 2729 for the bulk specific gravity of the specimen.

The stability outcome is the main parameter that is required to check for the SMA 20 mix and the results are shown in Table 3.

The Table 3 shows the stability against the bitumen content of the SMA 20 specimens with 25% increments of cockle shell ash as filler materials. The outcome displayed that the stability of the specimens is inversely proportional to the bitumen content of the specimens. The 0% of mineral filler or conventional specimen performed the maximum stability result (26.618-22.930 KN) whereas 100% of cockle shell ash as the lowest values (11.460- 9.503 KN). In addition, the increment of 25% of cockle shell specimens declined the stability value at 5.5 and 6.5 % of bitumen content. Moreover, there is less variation among the overall stability value of specimen with cockle shell ash in comparison to normal specimen at bitumen contents. All the stability results of the specimens are adequate as the values exceeded the minimum requirement of JKR standard, 2008 of 6.2 KN (Minimum stability value for SMA 20 is 6200 N or 6.2 KN). Therefore, the cockle shell ash proved that it can be applicable as filler material in the preparation of SMA 20 mix.

The flow values are another important factor for the SMA 20 Mix. The Table 4 represents the flow values attained from the study.

The above table signifies the flow of the specimens against bitumen content of the specimens. The results illustrated that the flow value of the various percentage of shell ash varies with bitumen content. The flow of the specimen is directly proportional to the bitumen content of the specimen by forming a straight line at normal, 50, 75 and 100% of shell ash as filler material. The normal specimen has the maximum flow values while least value is obtained in 25% of shell ash. Each percentage of cockle

Table 3: Stability results and specification for SMA 20 design

Parameters	Bitumen	Normal	25% of shell ash	50% of shell ash	75% of shell ash	100% of shell ash	JKR specification
Stability (KN)	5.5	26.618	18.587	13.632	11.46	10.629	6.2
	6	24.320	15.529	12.680	9.523	10.602	6.2
	6.5	22.930	13.615	12.629	9.503	9.003	6.2

Table 4: Flow results and specification for SMA 20 design

Parameters	Bitumen	Normal	25% of shell ash	50% of shell ash	75% of shell ash	100% of shell ash	JKR specification (mm)
Flow (mm)	5.5	3.579	3.287	3.383	3.472	2.922	2-4
	6	3.841	2.727	3.80	3.735	3.589	2-4
	6.5	3.907	3.85	3.886	3.924	3.982	2-4

Table 5: Voids in Mineral Aggregates results and specification for SMA 20 design

Parameters	Bitumen	Normal	25% of shell ash	50% of shell ash	75% of shell ash	100% of shell ash	JKR specification (%)
VMA (%)	5.5	24.471	23.351	21.428	21.766	21.258	Min 17
	6	24.978	24.744	24.380	23.039	21.963	Min 17
	6.5	26.094	25.474	25.142	23.656	23.263	Min 17

shell ash specimens has slight variation with various percentage of bitumen in it. The result obtained from this study is satisfactory as it ranges from 2.727-3.982 mm for the flow values which lie between the JKR requirements for SMA 20 of 2-4 mm.

The results obtained for Voids in Mineral Aggregates (VMA) in this study are suitable as it is greater than the required value for the VMA of the specimens and are shown in Table 5.

The table above showed the Voids in Mineral Aggregates (VMA) with bitumen content of SMA 20 specimens at various percentage of cockle shell ash as mineral filler content. The net results show that the increment in bitumen content leads to boost the VMA of the specimens in this study. The normal specimens obtained the optimum VMA values whereas 100% shell ash with lowest value. According to the result, 6.5% of bitumen content is the most sufficient bitumen rate as it obtained the peak VMA content while comparing to other percentages of bitumen of the specimen. The overall outcomes of the graph concluded that increment of mineral filler of cockle shell ash results in the decline of VMA of SMA 20 mix. The VMA result of this study is more adequate as the percentage of VMA is higher than 17% as mentioned in (Minimum VMA value for SMA 20 is 17%).

CONCLUSION

This study investigates the potential and suitability of shell ash as a filler material in SMA 20 Mix by Marshall Test parameters. The results proved that cockle shell ash can be exploited as mineral filler in SMA design as it meets the standard requirement. The other local materials such as coal fly ash, steel slag, limestone dust etc can be applicable as a filler material in SMA Mix by meeting the criteria from the laboratory test (Muniandy *et al*., 2006).

The stability values concluded that the increments of cockle shell ash declines the stability values of the design. The maximum stability values are obtained at the conventional and stability rate decline with increments of bitumen content. However, the stability values meet the standard requirements and cockle shell ash can be utilized as a filler material for SMA design. Moreover, the Palm Oil Fuel Ash also enhances the stability of asphalt mix by using it as a filler material (Ahmad *et al*., 2012).

The additional filler material showed that the low flow values compared to conventional specimens and the peak occurred at 6.5% of bitumen. There are variation in 75 and 100% of shell ash which might be because of manual compaction, maintain of the temperature during sample preparation etc. Though, the result met the requirement as it lies in the range of 2-3 mm and is appropriate for the filler material.

Void in Mineral Aggregates results are above the standard requirements for SMA specification. The results of additional mineral filler are lower than the conventional specimen and optimum is obtained at 6.5% of bitumen content. There is slight variation of VMA in normal specimen and specimen with cockle shell ash as filler material, although, this can be adequate to utilize as a filler material.

The net result conclude, it can be appropriate as the filler materials in SMA Mixtures while it has lower volumetric properties compare to specimen of normal or 0% of shell ash as filler materials as it showed the adequate result for parameters according to the standard.

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