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# Rutting resistance of asphalt mixture with cup lumps modified binder

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**Abstract.** Rutting is the most common pavement distress in pavement structures which occurs mainly due to several factors such as increasing of traffic volume, climatic conditions and also due to construction design errors. This failure reduced the service life of the pavement, reduced driver safety and increase cost of maintenance. Polymer Modified Binder has been observed for a long time in improving asphalt pavement performance. Research shows that the use of polymer in bituminous mix not only improve the resistance to rutting but also increase the life span of the pavement. This research evaluates the physical properties and rutting performance of dense graded Superpave-designed HMA mix. Two different types of dense graded Superpave HMA mix were developed consists of unmodified binder mix (UMB) and cup lumps rubber (liquid form) modified binder mix (CLMB). Natural rubber polymer modified binder was prepared from addition of 8 percent of cup lumps into binder. Results showed that all the mixes passed the Superpave volumetric properties criteria which indicate that these mixtures were good with respect to durability and flexibility. Furthermore, rutting results from APA rutting test was determined to evaluate the performance of these mixtures. The rutting result of CLMB demonstrates better resistance to rutting than those prepared using UMB mix. Addition of cup lumps rubber in asphalt mixture was found to be significant, where the cup lumps rubber has certainly improves the binder properties and enhanced its rutting resistance due to greater elasticity offered by the cup lumps rubber particles. It shows that the use of cup lumps rubber can significantly reduce the rut depth of asphalt mixture by 41% compared to the minimum rut depth obtained for the UMB mix. Therefore, it can be concluded that the cup lumps rubber is suitable to be used as a modifier to modified binder in order to enhance the properties of the binder and thus improves the performance of asphalt mixes.

## 1. Introduction

It is observed that the traffic volume on the highway keep increasing every year thus causing higher tire pressures, especially in the busy traffic areas such as tolls area, car park, intersections and at traffic light. The increases of traffic volume will lead to the permanent deformation of the pavements which is rutting. Rutting is the result of the progressive accumulation of permanent deformation of each layer of the pavement structure under repetitive loading [1]. Superpave mix design is the new method of mix design that is currently used in the US which is helping to improve the performance on the road. Superpave made its debut in Malaysia through the Kuala Lumpur International Airport (KLIA). Its directly correlates laboratory methods with pavement performance, which concern to the permanent deformation which are rutting and fatigue cracking. The tests are performed at the temperatures and aging conditions that more realistically represent the site conditions.

Previously, by using modified binder, the performance of asphalt mixtures can be improved and also the binder becomes more stable and stiffer at high temperature and more flexible at low temperatures. Some of the significant advantages of utilization of polymer modified binder are higher elastic recovery, a higher softening point, greater viscosity, greater cohesive strength and greater ductility [2]. Polymer modified binder also can increase the surface roughness of the aggregate and improved adhesion and degree of cohesion by creates an aggregate coating material thus produces superior asphalt mixtures [3]. Some previous studies had carried out to improve asphalt properties by using several kind of natural rubber latex such as field latex, concentrated latex and skim latex. They found that the the natural rubber latex is the best alternative for road making due to flexibility and stability improvement in asphalt pavement and extend service life of the road pavement. It was also found that the roads paving with natural rubber latex shall have more strength and durability than using unmodified binder [4 - 7]. Although there are many other materials that have been used as the modifiers in the bituminous mix such as crumb rubber, SBS, SBR latex, chemical additives and engineered binders but most of them are high cost materials.

Cup lump rubber or fresh latex is one of the modifiers that can be used in order to improve the binder properties. Cup lumps are obtained directly from rubber trees without going through any manufacturing process at the plant. This is why the researchers and engineers are looking for better materials in order to improve the bituminous mix. The uses of cup lumps rubber can be one of the solutions. It can be used as modifiers in the binder of bituminous mix in order to improve the binder mix properties. Therefore, in this study a new asphalt binder based on cup lumps rubber was investigated and characterized for possible improvements in the asphalt pavement mixes. It is believed that the cup lumps rubber modified bitumen would offer better performing asphalt mixes and such study is worthwhile for a sustainable road infrastructure that will provide a long lasting, safe and comfortable ride for the road users.

## 2. Experimental plan

The study focused on the evaluation volumetric properties and rutting performance of cup lumps rubber modified Binder (CLMB) of Hot Mix Asphalt (HMA) using Superpave methods. The Superpave mix design procedure involves careful material selection and volumetric proportioning as a first approach in producing a mix that will perform successfully. The aggregates were obtained from Blacktop Quarry, Rawang. The binder used in this study was 80/100 penetration grade supplied by SHELL. Superpave mix design was performed in order to prepare HMA Superpave mixtures for the mix design of SP 19 mm. The performance evaluation to be performed is rutting test. For rutting performance test, the laboratory designed mixtures was evaluated using the Asphalt Pavement Analyzer (APA).

### *2.1. Material properties*

Physical properties test were then conducted on the aggregates which conforms to the consensus and source properties as required in the Superpave system. The tests included Flat and Elongated particles (ASTM D4791), Abrasion Test (AASHTO T96)) and Aggregate Impact Value (AASHTO T96). Properties of aggregate were tested prior before preparing the asphalt mixture specimen. Table 1 and Table 2 shows the aggregate gradation and aggregate properties respectively. The aggregates meet the aggregate properties requirement. It can be concluded that Blacktop Quarry, Rawang, Selangor has a good quality aggregate. Thus, the aggregates are acceptable and suitable for use in road works.

**Table 1**. Aggregate Gradation.

| Sieve Size, mm | % Passing | % Retained |
|---|---|---|
| **25** | 100 | 0 |
| **19** | 96 | 4 |
| **12.5** | 81 | 15 |
| **9.5** | 75 | 6 |
| **4.75** | 55 | 20 |
| **2.36** | 43 | 12 |
| **1.18** | 32 | 11 |
| **0.6** | 23 | 9 |
| **0.3** | 13 | 10 |
| **0.15** | 8 | 5 |
| **0.0075** | 4 | 4 |
| **Pan** | - | 4 |
| **Total** | - | 100 |

**Table 2.** Aggregate Properties.

| Aggregate Test | Specification | Result |
|---|---|---|
| **Flakiness** | <20% | 3.1% |
| **Elongation** | <20% | 16.6% |
| **Aggregate Impact Value** | <45% | 21.75% |
| **LA Abrasion** | <45% | 25.35% |

*2.2. Binder modification*

The amount of binder used in the mixture is different, depending on the design. The binder used in this study was 80/100 PEN for control sample while PEN 80/100 + Cup lumps rubber for modified sample. The modified binder was prepared by mixing control sample with a proportion of cup lumps rubber. The most effective amount of cup lumps rubber was 8% by weight of binder, where it has great potential to improve the physical properties and the performance of bituminous mix [5]. The apparatus used to mix the polymer with the binder was hot plate and mechanical mixer. The modification process begun by heating and stirring the binder using the hot plate and mechanical stirrer at 500 rpm for 5 minutes. Then 8% of cup lump rubber by weight of binder was added slowly and mixed continuously for 60 minutes using mechanical stirring machine. The rotation speed of mechanical stirrer increases until the rotation reaches 1650 rpm.

*2.3. Optimum Binder Content (OBC)*

Superpave mix designs were conducted to determine design binder content. Superpave samples were prepared and tested according to AASHTO TP4 requirement and specification. Traffic level was selected based on common traffic level operating on most Malaysia highways. In this study, the traffic will be limited to medium to high roadway application. In Superpave system, medium to high traffic loadings is equivalent to between 3 to 30 million design equivalent single axle loads (ESALs) with 20 years design life. The design number of gyrations, Ninitial=8; Ndesign=100; and Nmax=160 was used to vary the compactive effort of the design mixture and was a function of traffic level. Selection of design asphalt binder content was obtained based on 4% air voids specimens. All other mixture properties were checked at the design binder content to verify that they meet the criteria. Table 3 shows the summary of the OBC determination process for both unmodified and modified samples. The results show that the modification binder with cup lumps rubber give more accurate result for the %VMA and %VFA which is 15.1 and 73.5 which is lesser than UMB sample. For the dust proportion the CLMB result is 0.9 which followed the criterion which is between 0.6 to1.2. While for percentage of theoretical maximum density (Gmm) is 85.9% lesser than 89% which is fulfill the requirement. Based on this result, it can be concluded that all the mixture properties meet the Superpave Criteria. The design binder content obtained for UMB is 5.7% and 5.1% for NRMB.

**Table 3.** OBC Determination.

| Mix Design Properties | UMB | CLMB | Criterion |
|---|---|---|---|
| **Air Void, %** | 4 | 0 | 4% |
| **VMA, %** | 15.8 | 15.1 | Min 13% |
| **VFA, %** | 74.7 | 73.5 | 65-76 |
| **Dust Proportion** | 0.8 | 0.9 | 0.6-1.2 |
| **$G_{mm}$, %** | 85.5 | 85.9 | <89 |
| **OBC, %** | 5.7 | 5.1 | - |

*2.4. Wheel tracking test*

The Asphalt Pavement Analyser (APA) equipment was used to evaluate the rutting resistance. The APA machine is the new version of the wheel tracker device. Generally, APA is a wheel tracking device that applies a vertical load to a steel wheel. The loaded wheels are applied to sample test of three pneumatic cylinders, where each of it is equipped with standard aluminium wheels. The total load from each of the moving wheel is shifted and transferred to a test sample through a pressurized rubber hose mounted along the top of the sample. The advantage of using APA is it can evaluate not only the rutting performance of an HMA mixture, but it also can determine the fatigue cracking and moisture susceptibility under certain condition of the service. Performance simulative tests have widely been used to compare the performance of a broad range of asphalt paving mixtures by modelling the anticipated traffic loads. Using these tests, stress conditions developed in the mixture under loading are not calculated, but similar to those applies to laboratory compacted samples and field cores to determine the performance figure 1 illustrates the Asphalt Pavement Analyser while figure 2 shows the samples after underwent the wheel tracking test.

**Figure 1.** Asphalt Pavement Analyser.

**Figure 2.** Samples after Testing.

## 3. Result and discussion

The samples were prepared by using Superpave Gyratory Compactor in order to compact 150mm samples of 75mm height. The samples were tested for 8000 numbers of wheels which is 60 cycles per minute and the computer software measured and average the rut depths. The rate of rutting determined by referring to the rut depth of the sample in millimetre. The equipment allows more realistic real world conditions to be simulated in the laboratory including temperature control. The unmodified samples and modified samples were inserted into two different moulds. Then the mould was put into the APA machine side by side. Two tubes were put on top of the samples in the mould. The samples then were conditioned at the testing temperature of 60°C with 690 kPa for three hours and another two hours for running the test. This test was simulated to the wheel passes within a pavement and the procedure is described in BS 598. Table 4 shows the comparison of rut depth at difference cycle for unmodified and modified samples.

**Table 4.** Rut Depth Values.

| Stroke Count | Rut Depth, mm | |
|---|---|---|
| | UMB | CLMB |
| **0** | 0 | 0 |
| **25** | 0.273 | 0.155 |
| **4000** | 3.763 | 2.289 |
| **8000** | 4.764 | 2.801 |

From the result, the modified sample shows more resistance towards rutting compare to unmodified sample, where the average rut depth is 2.801 mm at 8000 cycles. For unmodified sample (PEN 80/100), the average rut depth is 4.764 mm at 8000 cycles. The difference between both values of rut depth is 1.963 mm, which shows a significant difference. Higher rut depth indicates that the mixture has lower resistance towards rutting. This showed that the used of cup lumps modified binder can significantly enhance the performance of asphalt mixture in terms of rutting resistance. Figure 3 shows the graph of wheel tracking test for both control (red) and modified binder (blue).

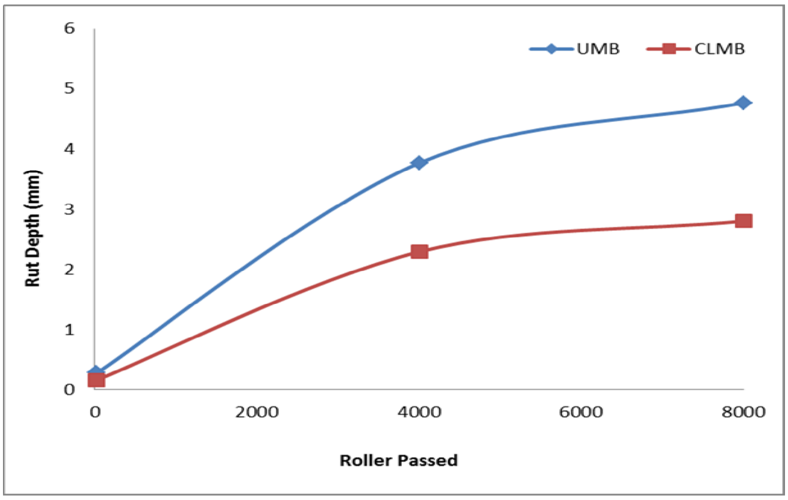


**Figure 3.** Rut Depth Versus Number of Cycle.

From the graph, it shows that modified sample has better rutting resistance compared to unmodified sample. At the beginning of the test, the rut depth values for both samples were zero. At 25, 4000 and 8000 stroke count, the rut depth value of the unmodified sample are 0.273 mm, 3.763 mm and 4.764 mm respectively. For the modified sample, the rut depth value at 25, 4000 and 8000 stroke count were 0.155 mm, 2.289 mm and 2.801 mm respectively. The differences in both samples at 25, 4000 and 8000 are 0.118 mm, 1.474 mm and 1.963 mm respectively. The differences increase as the stroke count increase. This shows that the increment of rut depth for modified sample is lower than unmodified sample. The properties of the unmodified sample mixture were not strong enough to provide the adequate bonding between binder and aggregate. The minimum rut depth obtained for the modified sample could reduce the rut depth by 41% compared to the minimum rut depth obtained for the unmodified sample. This higher resistance of modified sample to rutting compared to unmodified sample can be contributed by the greater elasticity offered by the cup lumps rubber particles which enhancing the rutting resistance. This finding is supported by previous studies [7] and [8] which indicates that the rut depths of modified sample are lower compared to the control sample. In addition, the natural characteristics of cup lump rubbers which is tends to glue itself strongly to the aggregates is also contribute to the better performance of the mixture. High amount of rut depth may be dangerous especially to the motorist. Road accident can happen when the tyre entering the rut area of the road.

## 4. Conclusion

In this study, the volumetric properties of Superpave mix design and rutting performance of the mix is evaluated to determine how resistance the control sample and modified sample is when used in asphaltic mixtures. Based on the findings, the following main conclusions can be drawn;

i. Local aggregates meet aggregate properties requirement. It can be concluded that Hanson quarry, Semenyih has a good quality aggregate. Thus, the aggregates are acceptable and suitable for use in road works.
ii. Locally aggregate gradations are suitable for Superpave mix design, since all mix design in accordance to Superpave system meet the Superpave requirements. The study also has proven the suitability of using Superpave mix design as the new system in our road pavement.
iii. The addition of cup lumps rubber in asphalt mixture was found to be significant, where cup lumps rubber has enhanced its rutting resistance due to greater elasticity offered by the cup lumps rubber particles. The minimum rut depth obtained for the modified sample could reduce the rut depth by 41% compared to the minimum rut depth obtained for the unmodified sample.

Cup lumps rubber also helps to increase the performance and the ability of asphalt mixture to improve its action toward traffic loading hence increase life span.

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