Marshall properties and rutting resistance of hot mix asphalt with variable reclaimed asphalt pavement (RAP) content

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Abstract. Hot mix recycling is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials to produce hot mix asphalt mixtures. This paper details a laboratory study in which the effects of different RAP contents were evaluated on the performance of hot recycled mixes. The objective of this study is to evaluate the rutting resistance of asphalt mixes containing different percentages of RAP. The Marshall mix design method was adopted in this study to determine the OBC for the asphalt mixes containing four aggregate combinations with RAP contents of 0% (control), 15%, 25% and 35%. Volumetric analysis was performed to ensure that the result is compliance with specification requirements. The resilient modulus test was performed to measure the stiffness of the mixes while the Hamburg wheel tracking test was used to evaluate the rutting performance of these mixes. The results obtained showed that there were no substantial differences in volumetric properties, stability values and stiffness properties between the control mix and recycle mixes. It can be concluded that recycled mixes performed as good as the performance of conventional Hot Mix Asphalt (HMA) in terms of resilient modulus and rutting.

1. Introduction

The pavement industry has long emphasized the need to reuse RAP materials obtained from deteriorated roads as these materials still possess desirable properties to be used for the surfacing layers, subject to the limitations set in the specification used. With the dwindling supply of new resources and spiraling cost of materials, the use of RAP is a suitable way to conserve non-renewable resources, that is aggregates and bitumen used for asphalt mixes [1,2]. The increase in asphalt materials prices has led the road construction industry to strive for the use of higher percentages of RAP to reduce the cost of road projects. A higher addition of RAP should enhance the value of the recycled pavements and have the potential for reducing the quantity of waste materials [3].

The use of RAP in asphalt concrete also adheres to the requirement of sustainable solutions in pavements because it is both environmentally friendly and cost effective [4]. By adding RAP to asphalt mixtures, it is estimated that the environmental impact of production is reduced by 23%. Furthermore, RAP presents a significant material cost reduction. Quality virgin aggregate material is becoming increasingly difficult to find and purchase. Therefore, the use of RAP can offset costs and allow road authorities to build and rehabilitate more roadways with similar budget capacities.

Most road authorities allow the incorporation of not more than 30% of RAP in hot mix asphalt (wearing course) to avoid any detrimental effects on the mix properties [5,6]. For example, the Illinois...
Department of Transportation allows up to only 30% RAP in binder and surface mixtures depending upon the traffic level present on a given roadway. This is because RAP is usually considered to be a stiff material primarily due to oxidative hardening and other aging mechanisms it undergoes while exposed to the environment during its service life. Consequently, the increased stiffness in RAP may lead to various forms of cracking failures which deter producers and road authorities from further increasing the RAP content [7].

The Asphalt Institute suggests that when 20 percent or less RAP is used in a mix, no change in asphalt grade is required [8]. However, for mixes with greater than 20 percent RAP, a drop in one grade (softer asphalt cement) is recommended to compensate for the higher viscosity of the oxidized binder. Many road authorities use the same grade of asphalt cement regardless of the RAP content.

The Asphalt Institute’s manual on mix design methods for asphalt concrete provides a method to determine necessary mix design characteristics (such as stability, flow, and air voids content) for the Marshall mix design method. The final mix design proportions for the recycled hot mix paving mixture will be determined by completing mix design testing using standard procedures to satisfy the applicable mix design criteria. Additional virgin aggregates may be required to satisfy the gradation requirements to improve stability and to limit the RAP content in recycled hot mixes. The Marshall mix design method was adopted in this study to determine the optimum binder content (OBC) for the asphalt mixes containing four aggregate combinations with RAP contents of 0% (control), 15%, 25% and 35%. The objective of this study is to evaluate the rutting resistance of the asphalt mixes containing different percentages of RAP.

2. Methodology
The samples for control mix and recycled mixes were prepared based on the Marshall mix design method in accordance with ASTM D1559. The mix design used AC14 aggregate gradation in accordance with Public Works Department of Malaysia’s (PWD Malaysia) Specification for Road Works [9], with the range of binder content from 4.0% to 6.0%. A total of 15 samples each were prepared for the control mix (100% virgin aggregates) and the asphaltic concrete mixes with RAP contents of 15% (RAP15), 25% (RAP25) and 35% (RAP35) by weight. All the samples were compacted with 75 blows on both surfaces of the samples using the Marshall compactor. Volumetric properties and analysis were carried out to determine the optimum binder content (OBC) for the control mix and recycled mixes. The optimum binder content value was used to prepare samples for the rutting resistance test. The Hamburg Wheel Tracking test was carried out in accordance with AASHTO T324 to evaluate the rutting susceptibility of mixtures under high temperature [11]. The equipment used for this test was the Asphalt Pavement Analyzer (APA) that is capable of running Hamburg Wheel Tracking tests. The test was run at a rate of 50 passes of a steel wheel per minute with a load of 705 + 22N. This test was conducted until the maximum number of 8,000 passes has occurred or until the maximum rut depth value of 20mm has been reached.

3. Result and discussion
Initial laboratory tests were conducted to determine the physical properties of the materials used. Marshall mix design was conducted to determine the Marshall properties and the optimum binder content (OBC) for control mix and RAP mixes. The result of resilient modulus test and rutting resistance test as performance tests were then compared between the control mix and RAP mixes.

3.1. Comparison of RAP Aggregate and Virgin Aggregate Properties
The results of Aggregate Abrasion Value, Aggregate Impact Value, Aggregate Crushing Value and Specific Gravity for recycled aggregate and virgin aggregate is shown in table 1. The LA abrasion value, aggregate impact value, aggregate crushing value and specific gravity of recycled aggregate are higher than the virgin aggregate. This may be due to the fact that the recycled aggregate was exposed to traffic loadings for a long period of time, reducing the strength of the aggregate. However, the result
shows that the properties of recycled and virgin aggregate are within the specification requirements. This indicates that the aggregate is suitable to be used for the preparation of the mixtures.

**Table 1. Basic Properties of virgin aggregate and RAP aggregate.**

| Aggregate Properties          | Recycled Aggregate | Virgin Aggregate | PWD Malaysia’s Requirements |
|-------------------------------|--------------------|-----------------|---------------------------|
| LA Abrasion Value (%)         | 25.00              | 23.00           | <25                       |
| Aggregate Impact Value (%)    | 21.80              | 19.40           | <25                       |
| Aggregate Crushing Value (%)  | 24.31              | 22.24           | <25                       |
| Bulk Specific Gravity, Gsb (g/cm) | 2.625            | 2.648           | -                        |
| Apparent Specific Gravity, Gsa (g/cm) | 2.711            | 2.705           | -                        |
| Water Absorption (%)          | 1.063              | 0.626           | <2.0                      |

3.2. Marshall properties

Marshall tests were conducted to determine the volumetric properties of mixture. The volumetric properties determined included bulk specific gravity, air voids, voids filled with bitumen (VFB), stability and flow. The Optimum Binder Content (OBC) for the control and RAP mixes were determined from the individual plots of bulk density, air void, voids fill with asphalt (VFA), stability and flow versus percent asphalt content.

There are significant effects on the Marshall properties with the inclusion of RAP in the asphalt mixes. Marshall test results showed that the Marshall flow, VFA and Bulk SG increased as the RAP content increased. However, Marshall stability value and air voids in mix showed a decreasing trend with increasing RAP content. The results are shown in figures 1 to 5 below. These trends could be attributed to the existing bitumen in RAP which influences the properties as its percentage increases. However, the results and analysis showed that there is not much variation between conventional mixes with the RAP mixes and all the mixes satisfy the specification requirements for the Marshall tests.

![Figure 1. Bulk SG versus binder content for different RAP content.](image1)

![Figure 2. Air Voids versus binder content of different RAP content.](image2)
3.3. Marshall properties and determination of optimum binder content (OBC)

The OBC for control mix and RAP mixes were taken as the arithmetic mean of the value of binder content from the five smooth curves plotted and the value was checked with the limits set in PWD Malaysia’s specification. Table 2 shows the Optimum Binder Content (OBC) for control and RAP mixes. The OBC decreased as the RAP content increased. The OBC for control mix, RAP15, RAP25 and RAP 35 are 5.34%, 5.22%, 5.10% and 4.88% respectively. The result obtained showed that there were no substantial differences in Marshall Properties.
Table 2. Results for marshall mix design for different RAP contents.

| Properties     | Control Mix | RAP 15 | RAP 25 | RAP 35 | PWD Malaysia’s Specification |
|----------------|-------------|--------|--------|--------|-----------------------------|
| OBC (%)        | 5.34        | 5.22   | 5.10   | 4.88   | -                           |
| Bulk S.G       | 2.388       | 2.393  | 2.399  | 2.401  | -                           |
| Air voids (%)  | 4           | 4      | 4      | 4      | 3-5                         |
| VFB (%)        | 75          | 75     | 75     | 75     | 70-80                       |
| Stability (kN) | 22          | 18     | 16     | 18     | >8                          |
| Flow (mm)      | 3.0         | 2.95   | 2.92   | 2.95   | 2-4                         |

3.4. Rutting resistance test
The result for rutting test for the asphalt mixes with different RAP contents is shown in figure 6. The rut depth increased with the increase in the RAP content of the asphalt mix. The control sample exhibit the highest resistance to rutting compared to mixes containing RAP with a depth of 3.4 mm at 8000 wheel passes. RAP15 reached a rut depth of 3.7 mm at 8000 wheel passes, followed by RAP25 and RAP35 with rut depths of 4.2 mm and 4.4 mm respectively. The higher rut depth indicates that the mixes with higher RAP content have lower resistance to rutting. This increase in rut depth may possibly be due to the effect of the existing binder in the RAP which increases the deformation of the mix and increases the rut depth.

![Figure 6. Rut depth for Hamburg wheel tracking test for different RAP content.](image)

4. Conclusion
From this study, the following conclusions can be made:

- The laboratory result for the physical properties shows that the properties materials used in this study satisfy the specification requirements of the Public Works Department of Malaysia. However, from the tests carried out, the RAP aggregate was found to have lower strength than the virgin aggregate. This is due to the RAP material which was exposed to the environment and traffic load for a long time.
From the Marshall test result, the OBC for control mix is 5.34%, RAP 15 is 5.22%, RAP25 is 5.10% and RAP35 is 4.88%. The OBC for mixes containing RAP reduced as the amount of RAP increased, possibly due to the influence of the existing binder in the RAP. It can be concluded that the use of high percentages of RAP could influence the properties of the Marshall mix design.

The Hamburg wheel tracking test showed that the rutting resistance also decreased when the RAP content increased. The control mix sample shows the highest rutting resistance, followed with RAP15, RAP25 and RAP35. However, the difference in rut depth between the control sample and RAP mixes is minimal, indicating that the mixes with RAP have comparable rut resistance compared to control mix.

It can be concluded that the rutting performance of mixes containing RAP of up to 35% by weight is comparable to asphaltic concrete mixes containing virgin aggregates based on the Hamburg wheel tracking test carried out in the study. However, a detailed study and investigation is required for higher RAP contents to ensure compliance with specification requirements.

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