Performance Evaluation for Rutting and Moisture damage of Hot Asphalt Mixtures using High Percentage of Recycled Asphalt Pavement Material

Waqas Rafiq¹²*, Madzlan Bin Napiah¹, Muslich Hartadi Sutanto¹, Wesam Salah Alaloul¹, Muhammad Imran Khan¹ and Abdulnaser Al-Sabaeei¹

¹ Department of Civil and Environment Engineering, Universiti Teknologi Petronas, Malaysia
² Department of Civil Engineering, COMSATS University Islamabad, Wah Campus, Pakistan
* Corresponding author: waqas_18000277@utp.edu.my

Abstract: Recycled Asphalt Pavement (RAP) usage has increased a lot from the last two decades. World highway agencies are attempting to use higher quantities of RAP to cope up with not only economic and green environment but also to save natural resource and comparable or even better performing hot mix asphalt (HMA) mixtures. Continuous damages of flexible pavements like rutting, moisture damage and thermal cracking reduces the pavement performance as well as riding quality. Studies have shown that high amount of RAP mixtures has impact on the fatigue performance, stiffness and permanent rut deformation characteristics of hot mix asphalt. Therefore, this study was done by using experimental approach to check the rutting and moisture damages of RAP combined with HMA by using Hamburg Wheel-tracking Device (HWTD). The hot mix asphalt designs included a control or having mix with 0% RAP and six samples of HMA with 10%, 20%, 30%, 45%, 60% and 100% recycled asphalt mixture to get an optimum percentage on which performance testing was done, after finding out the corresponding volumetric properties of mixtures stability and flow parameters of RAP mixtures. In this research all tested mixtures with RAP showed better performance than the virgin mixes.

1. Introduction
Transportation infrastructure is the cornerstone for the prosperity of any developing country. Roads are main source of transportation for public and freight movement. Road infrastructure forms a remarkable part in social and economic prosperity of any country. Pavements when designed according to the specification and standards will be durable structure to sever the desire design life. These well designed, properly constructed and maintained roadways sever the needs and satisfy the road users while daily commuting and their long trips as well. The use of recycled asphalt pavement (RAP) materials have regularly increased. The need to recycle old pavement material is having not only cost benefits but also from a rise in environmental perspective. In an age which every organization desire to adopt more workable approaches, asphalt pavement material which includes (binder and aggregate) reuse, is a way forward in preserving pavement systems. Researchers had looked at many performance measures and parameters that include the rutting and cracking susceptibility of RAP incorporated mixtures for their potential benefits. Pavement deterioration is not only because of traffic loading but also important factor is the binder aging [1].

During the last few decades continuous increase in traffic volume has resulted in premature pavement. Premature rutting is one of the major pavement distresses of flexible pavement which is faced by country because of high axle load and more temperatures. Rutting in flexible pavements be subject
to many factors including: aggregate gradation and quality, asphalt mixes performance, binder properties, optimum binder content, air void in compacted mix, compaction level, environmental conditions including road traffic, temperature and moisture, traffic repetitions, the sub-layers and the sub-grade soil’s bearing capacity [2].

Financial and eco-friendly thoughts have provoked the recycling of plastic, steel, aluminum and many other materials [3]. Now one of these recyclable materials is recycled asphalt materials. In conventional hot asphaltic mixture design RAP hardly increases 20% to 25% in addition hot in place pavement recycling (HIPR) or cold in place pavement recycling (CIPR), which can incorporate up to 80% to 100% RAP [4]. Variability in aggregate gradation is major causes for RAP’s materials limited use introduces when RAP stocks are not correctly managed, divided and processed to reduce inconsistency such as segregation. Due to economic crises joined with environmental concerns, transportation departments in United States are being required to increase the amount of RAP to concrete pavements. Higher amount of RAP usage in asphaltic pavement is most likely to impact durability and structural performance of the pavements [5]. Researches have shown that high amount of RAP impact on the performance properties like permanent deformation, fatigue and fracture characteristics of HMA [6].

The asphalt concrete industry has always suggested reusing the road material. The initial recycled asphalt pavement had been practiced as early as 1915 but major utilization of RAP in hot asphalt mix really started in the middle of 1970s because of rise in asphalt binder cost as the result of oil ban. Along with RAP, recycles asphalt shingles (RAS) is being currently used in Texas states [7]. The use of RAP and RAS can considerably decrease the cost of HMA laying and paving, conserving energy and protecting the environment. RAP and RAS binders are stiffer than virgin binders combining stiff material with virgin materials makes the designed mixtures cause cracking and leading to problem i.e. durability, which is major concerns of RAP and RAS mixtures. So, it is important to address the premature cracks in order to make efficient use of recycled materials [8].

Recycled asphalt mixtures failures are mostly linked with aged binder in the mix. Increase in mixture stiffness is because of very stiff and less elasticity available in binder. These are few of the important reasons for unwillingness for government agencies to allow usage of high RAP content. Similarly, the rutting failure and damage cause due to water is also very prominent issues in new asphalt pavement. So, to determine and evaluate the rutting behavior and nature in hot mix asphalt many laboratory test procedures have developed over time. Many methods are still in use after years and development also is in process for many others. From last thirty years Hamburg Wheel Tracker Device (HWTD) is in use to estimate the performance properties of flexible pavements. Main objective of this equipment is used to evaluate the performance of asphalt mixes under standard heavy load and different environmental conditions [9].

The permanent deformation characteristics were evaluated when asphalt samples are subjected to continuous repeated loading by mechanized wheel. This give good idea to road designers to choose the right optimum design mixture properties by correlating the mix properties and rutting propensity. Using HWTD for performance evaluation some highway authorities have major concern on its less repeatability in its performance tests. Standard procedures are being addressed in AASHTO T324 but how to prepare the standard specimen is not discussed [10]. The wheel tracker can measure the rutting and moisture damage properties simultaneously in terms of stripping point, when steel moves on the surface of asphalt specimen that is immersed in water and temperature can vary from room temperature up to 70 °C [11].

The recycling technique was first introduced in Malaysia Since mid-80’s, as one of the concepts of alternative road rehabilitation. Working on cold in-place recycling started in Malaysia almost 20 years ago, until 1993 when it was the private sectors which took the matter seriously by obtaining machines from Germany, the United States and Canada for purpose-built recycling. The progress of the recycling technology in the country had motivated private sector with a strong backing from the government through the Malaysia Public Works Department to accommodate and build the federal roads in Malaysia with the same technology [12]. The Malaysia Government has allocated a huge amount of money over the years to maintain, rehabilitate and improve the quality of the road pavements in Malaysia, approximately RM5 billion has been spent between 2001 and 2010 to keep sustaining all the Federal
roads in Malaysia [13]. Malaysia has estimated length of road network currently present is approximately 144,403 kilometers, of which 116,169 kilometers is paved includes federal roads of 49,935 km and 1,821 kilometers (1,132 mi) is expressways. Currently RM926 million is assigned for building and upgrading roads including in rural areas and bridges. Large amount of resources in terms of money to keep improving and maintaining the roads in good user quality especially Federal roads in Malaysia. Higher cost of road preservation, increase in demands of road users, change in huge volume of traffic, insufficient capital and less budget allocated, the concerning clients which include the government authorities and private stakeholders are looking for the most suitable road restoration method, which can produce high-quality pavement performance and enable them to achieve potential cost saving and the best value for money [14]. Therefore main objective of this paper is to utilize the RAP in hot mix asphalt to evaluate the rutting susceptibility and moisture damage of Hot Mix Asphalt (HMA) mixtures containing RAP content by using Hamburg wheel-tracking device to get the optimum amount that can be recommended for highways.

2. Experimental Program

2.1. Materials
For testing the selected aggregate gradation was of JKR wearing course AC 14 according to standard specification for road works to prepare the dense graded surface course mixes [15]. Aggregates were supplied from a quarry in Ipoh, Malaysia and 60/70 bitumen penetration grade was used, which was collected from local refinery. RAP material was collected from Kamunting Premix Plant from PLUS highway and dumped there in form of milled material. After complete calculation of optimum asphalt binder content and finding aggregate gradation of rap material, samples in the laboratory were prepared. The gradation selected for mixture preparation is plotted with passing percentage verses sieve sizes is shown in Figure 1. Asphalt percentage present in RAP material was determined through asphalt extraction by using AASHTO T 319-03 and ASTM D7906 –14 [16]. Table 1 presents the gradation of virgin and RAP materials after extraction procedure. As per AASHTO standards, chlorinated solvent was used to extract bitumen from RAM material. The optimum asphalt content used in RAP materials can be determined from these methods as well as additional quality tests on extracted aggregates can be performed. The extraction could be performed for both HMA and RAP samples using Centrifuge extraction method. The RAP binder content was found to be 4.5% after aging on site.

![Figure 1. Gradation plot with JKR Specified limits](image-url)
Table 1. Virgin Binder and Recycled Asphalt Pavement Gradation (after extraction)

| Sieve size (mm) | Virgin Percent passing | RAP-PLUS Highway Percent passing |
|-----------------|------------------------|---------------------------------|
| 20              | 100                    | 96.87                           |
| 14              | 95                     | 75.46                           |
| 10              | 80                     | 65.01                           |
| 5               | 56                     | 48.62                           |
| 3.35            | 47                     | 41.15                           |
| 1.18            | 26                     | 23.14                           |
| 0.425           | 18                     | 12.15                           |
| 0.15            | 10                     | 5.00                            |
| 0.075           | 6                      | 1.95                            |

Before using RAP in HMA mixture it was essential to evaluate the extracted binder properties using AASHTO T 49-06, AASHTO 51-08. Various blends of RAP extracted binder and virgin/fresh binder were prepared and tested for basic properties such as, penetration and ductility following ASTM D5 and ASTM D113. The results have been demonstrated in Table 2. Literature research showed that up to 20% Low RAP content can be designed for mixtures without changing the binder penetration grade.

Table 2. Penetration and ductility for all the blends

| RAP/Virgin ratio | Penetration (cm) | Ductility (cm) |
|------------------|------------------|----------------|
| 0/100            | 64               | 118            |
| 10/90            | 58               | 105            |
| 20/80            | 55               | 97             |
| 30/70            | 47               | 87             |
| 45/55            | 42               | 75             |
| 60/40            | 29               | 64             |
| 100/0            | 22               | 16             |

2.2. Gradation for varying proportions of RAP

The main objective of this research was to study the effect of recycled material in the mix on rutting and moisture damage. So, for this the RAP percentage was mixed by 0%, 10%, 20%, 30%, 45%, 60% and 100% in HMA mix. Their volumetric analysis was performed to determine the optimal value RAP content to be used in the mix. Marshall Mix design procedure for calculation of stability flow values and volumetric was used. Therefore, varying the RAP percentages and aggregates on sieves were calculated according to the JKR blended mix gradation of hot recycling, percentage passing obtained from performing the gradation analysis of extracted RAP aggregate which is shown in Figure 2. Upper and lower limits of blend along with RAP 100% percentage passing verses sieve sizes aggregate gradation is plotted.
2.3. Mixing and preparation of specimens

According to the ASTM D6927-15 standard procedure for determining performance properties like volumetrics, stability and flow of Hot asphalt mix, Optimin binder content (OBC) is calculated before the specimen’s preparation for performance testing using Marshall mix design procedure. Therefore, following the standard procedure for the preparation of mix samples as per ASTM D6926 using Marshall Apparatus. For each RAP percentage, 3 numbers of samples of 100 mm diameter were prepared and using average values volumetric were determined.

According to ASTM D 6926 the amount of aggregates and bitumen required for 100 mm diameter sample is 1200 gm. The required amount of aggregates against respective sieves were calculated and aggregates were oven dried at temperature range of 105 °C to 110 °C. Equations 1, 2 showed the bitumen required for each specimen preparation.

\[ W_A + W_B = W_T \]  \hspace{1cm} (1)
\[ W_B = p/100 \times W_T \]  \hspace{1cm} (2)

Where,
\( W_A \) = Weight of Aggregate
\( W_B \) = Weight of Bitumen
\( W_T \) = Total Mix
\( p \) = Binder percentage

Calculating of aggregate for respective sieves and bitumen calculation, the mixing of aggregates and binder was carried out in mixing machine (ASTM D 6926). The temperature range between 160 °C to 165 °C was maintained for performing the mixing. Segregation is common issue so aggregate and bitumen mix was poured in the Marshall 100 mm mold in almost two equal portions. 75 number of blows were done on each sides of specimen for compaction using mechanical hammer. For preparation of samples for wheel tracker tests. The required quantity of aggregates for preparing 150 mm diameter gyratory compacted specimens was 6000gm. Compaction of specimens was done by providing 125 gyrations. As RAP is incorporated in specimen’s preparation so required amount of RAP is used. Three replicates were prepared for every RAP percentage using 60/70 grade asphalt for both wet and dry condition of Hamburg wheel tracker test. Figure 3 shows the compacted samples extracted from mold. Specimens were saw cut from top and bottom portion of each specimen to obtain a standard specimen of 1.5-inch height and 6-inch diameter. Saw cut specimens for wheel tracker test are shown in Figure 4.

**Figure 2.** Blended Gradation plot of RAP percentages with JKR Specified limit
3. Results and Discussion

4-inch diameter specimens (having 14 mm NMAS) were prepared using Marshal testing procedures as per ASTM D-6926. Mixtures were designed for heavy traffic loading. Table 3 presents the volumetric and stability results of all mixtures with various percentages of RAP contents. As per JKR design specification, the minimum stability of 12 kN and flow value in between 2 to 4 mm, all mixtures satisfy the minimum requirements. Table 3 illustrates the variability in the volumetric properties of mixtures due to the increase in RAP content. The results showed that the specimen stability increases with an increase in RAP content and is approximately approached double for 100 percent RAP content.

Table 3. Marshall Mix design Volumetric properties for all RAP containing mixtures

| RAP (%) | Air voids (%) | VFA (%) | Stability (KN) | Flow (mm) |
|---------|---------------|---------|----------------|-----------|
| 0       | 4.10          | 71.20   | 15.30          | 3.92      |
| 10      | 3.95          | 72.66   | 15.93          | 3.74      |
| 20      | 3.97          | 74.17   | 16.92          | 3.56      |
| 30      | 3.48          | 73.99   | 18.93          | 3.43      |
| 45      | 3.53          | 76.45   | 19.90          | 3.32      |
| 60      | 3.62          | 78.20   | 21.21          | 3.10      |
| 100     | 3.70          | 79.08   | 24.65          | 2.98      |

Controlled (virgin aggregate and bitumen) and RAP modified specimens for AC 14 gradation (NMAS 14mm) were tested against rutting propensity at room temperature in dry mode of wheel tracker machine. Figure 5 shows that the rut depth which is plotted against 20,000 number of passes of wheel tracker. Figure 5 clearly showed that the rut depth of specimen obtained after 20,000 numbers of passes for controlled mixtures is higher than the rut depth found with specimens having RAP content varying from 10% to 100%. The maximum rut depth attained for controlled specimens is -1.12 mm whereas the maximum rut depths obtained for 100% RAP percentage specimens is -0.14 mm respectively. The acceptable range for rut depths was set to be below 20mm failure values so obtained values for all specimens either control or RAP containing mixtures were very well in range.
Controlled and RAP modified specimens of AC 14 gradation were tested against moisture susceptibility in wet mode at room temperature in Hamburg Wheel Tracking Device (HWTD) AASHTO T 324-04 (2007). The HWTD is having three modes on which tests can be conducted that is dry, air and wet mode [17]. Utilizing the wet mode of HWTD, specimens were submerged underwater at 50°C temperature [18-19]. After completing 20,000 numbers of passes underwater and wet conditions the graph is plotted against the number of passes and rut depth shown in Figure 6 shows that controlled mixture rut depth is more as compared to rut depth obtained from specimens having RAP content. The mixtures containing 10% to 100% RAP shows acceptable range of rut depth, as the rut depth at failure was set at 20 mm to evaluate the effect of striping in the mixtures. It is because the RAP materials are stiffer than virgin mixtures. Moisture damage results show that HMA with a control mix is having stripping inflection point above 10000 passes that is 12000 passes, so only routine maintenance is required before the design life [20-21].

Figure 6. Rut depth versus number of passes

4. Conclusions
Laboratory experiments were conducted on JKR wearing course AC-14 mixture containing 0, 10,20,30,45,60 and 100 percent fractionated RAP for rutting susceptibility and moisture damage using Hamburg Wheel Tracking Test. From the tests of binder and mix following conclusions were drawn:

1. The Marshall stability generally increases shows good linearity with increment in RAP content. Mixtures containing 100% RAP stability is almost 1.5 times the stability of the control mixtures.
2. The binder recovery and its blending with virgin/fresh binder were tested for penetration and ductility tests. The results of penetration and ductility values showed that up to 45% RAP, aged binder still has some viscoelasticity. Since the 60/70 binder grade is selected, that can aid as rejuvenating agent in the asphalt mixture when the less amount of RAP is used in mixtures.

3. The resistance to rutting for Hot mix Asphalt containing RAP improved in comparison to control mixture.

4. Moisture susceptibility tests indicated that with higher inclusion of RAP samples exhibit lower rut depths.

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