Title: Performance of Recycled Asphalt Pavement Mixes – Comparing New Zealand Experience to American Experience

Authors: Sachi Kodippily
Glynn Holleran
Irina Holleran
Theunis F.P. Henning, PhD
Douglas Wilson, PhD

1 Department of Civil and Environmental Engineering, The University of Auckland, Private Bag 92019, Auckland, New Zealand.
2 Fulton Hogan Ltd, Private Bag 11900, Auckland 1542, New Zealand.

Address for correspondence:
Sachi Kodippily
Department of Civil and Environmental Engineering, The University of Auckland
Private Bag 92019, Auckland, NEW ZEALAND
E-mail: sachi.kodippily@auckland.ac.nz
Telephone: +64 9 373 7599, Fax: +64 9 373 7462

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ABSTRACT

Developing technologies that provide sustainable solutions for future pavement construction is vital given the ever-increasing demand on the supply of bitumen and good-quality pavement construction materials. Recycled Asphalt Pavements (RAP) is a technology that presents many benefits in terms of both cost and environmental savings. The presented paper investigated the use of RAP in New Zealand with the aim of establishing RAP as a standard pavement construction technology. The study findings were used to establish performance standards for RAP mixes in New Zealand.

In this study, laboratory testing was undertaken to characterise the performance of asphalt mixes containing different quantities of RAP. Samples were prepared from three mixes containing 15% RAP, 30% RAP, and a control mix, and the samples were subjected to dynamic modulus, flow number and overlay testing using an Asphalt Mixture Performance Testing machine. The inclusion of 30% RAP resulted in notable increases in the deformation resistance of an asphalt mix, while the inclusion of 15% RAP only had marginal improvements to the deformation resistance of an asphalt mix. The presence of 30% RAP however increased the susceptibility of asphalt mixes to reflective cracking. No notable difference was observed between the cracking susceptibility of the 15% RAP mix and the control mix. The research results provide a valuable understanding of the performance of RAP and through this research new testing protocols were established for the use of RAP in the New Zealand context.

Key words: RAP, recycling, asphalt, pavements, cracking, dynamic modulus
INTRODUCTION

Recycled Asphalt Pavements (RAP) are a sustainable paving method that has many advantages to the pavement industry. Recycled asphalt pavements are constructed using a combination of reclaimed asphalt pavement material and new paving material, where during rehabilitation of pavements the asphalt surface layer is milled and combined with new asphalt binder and aggregate to create a recycled paving mixture. The use of RAP as an alternative to new Hot Mix Asphalt (HMA) paving mixes reduces the requirement for quality binder and aggregates for pavement construction and the recycling of existing material preserves valuable resources. In addition to relieving pressure on bitumen supplies, the RAP technology has many benefits by providing both economic savings and environmental benefits. The attractiveness of RAP as a sustainable paving material means an increasing number of pavement practitioners and contractors are utilizing this technology as a method to relieve the pressures on the demand for quality bitumen and aggregates. It has been estimated that in the United States of America (USA) approximately 80% of reclaimed asphalt is recycled as pavement material \(^2\) and in Australia it is estimated that approximately 50% of reclaimed asphalt is being used to produce RAP mixes \(^1\). In New Zealand, RAP has been utilized in pavement construction for several years, although the allowable proportion of reclaimed material in a RAP mix is currently limited to 15% \(^23\). The use of higher proportions of reclaimed material requires the approval of NZ Transport Agency, where it is necessary to demonstrate adequate performance of the mixes in trial settings in order to achieve approval for use in practice \(^10\). The need for approval to use higher quantities of reclaimed material can limit the widespread use of higher quantities of reclaimed material. Many economic benefits have been observed by the use of 15% of reclaimed material, and it is expected that these benefits can be further increased if higher quantities of RAP are used. It is imperative that testing protocols and performance limits are established for the context of New Zealand’s paving practices that can demonstrate the performance of RAP mixes in order to encourage the use of higher quantities of RAP in practice.

OBJECTIVES AND SCOPE

The primary objective of the presented study were to characterise the deformation and cracking resistance of HMA mixes containing different proportions of RAP for the New Zealand context. The performance assessments that were conducted as part of this study were based on laboratory prepared samples and it was intended that the results from the laboratory testing would form the basis for establishing performance limits for RAP mixes. Presented in this paper are the initial results from a larger study that is investigating the performance of RAP mixes for application on New Zealand pavements. The results that were obtained from the presented study were benchmarked against observed RAP performance in the United States of America in order to validate the study findings.

CHARACTERISING THE MECHANICAL PROPERTIES OF RAP MATERIAL

The inclusion of RAP in the production of Hot Mix Asphalt (HMA) paving mixes alters its characteristics, specifically, the deformation and fatigue performance of HMA. By its nature, RAP is old material and the binder that is present in RAP is aged and therefore is stiffer. The inclusion of this aged binder to virgin HMA materials results in a modified mix that has the potential to be stiffer. The increased stiffness provided by RAP has its benefits, particular
when considering the deformation resistance of paving mixes. It has been documented that
the inclusion of higher quantities of RAP notably increases the dynamic modulus of HMA
mixes when compared to virgin HMA mixes (5, 9). Some studies have reported that the
inclusion of small quantities of RAP, for example 5% to 10% has similar deformation
performance properties as completely virgin HMA mixes, although as the RAP proportions
increased, the improved deformation resistance became more noticeable (7). The increased
stiffness provided by RAP is extremely beneficial as it provides the necessary stiffness
requirements for pavement layers while at the same time minimising the need for good-
quality pavement aggregates. While the increased stiffness is a positive aspect of RAP, the
aged binder in RAP can also have negative effects on its performance, particularly when
considering the fatigue cracking resistance of RAP. A reduction in the fatigue cracking
resistance of RAP mixes has been observed in some studies, where it has been found that
when high quantities of RAP were used, such as 20% - 40%, the fatigue cracking resistance
of the HMA mixes reduced in comparison to virgin HMA mixes (8), although when lower
quantities of RAP, for example 10% were used there was no noticeable effect on the fatigue
cracking performance (6, 12).

MIX DESIGN METHOD

Performance testing was conducted on three HMA mixes, where one mix was HMA with
30% RAP, the other mix was HMA with 15% RAP, and the third mix was a control mix
containing 100% virgin HMA. The mix design process of the test mixes were conducted
according to the specifications set out in NZTA M/10:2010 (23). The mix designs were
optimised for the RAP contents of the mixes and incorporated differing job-mix formulae,
which were within the mix envelopes set out in NZTA M/10:2010. All three test mixes were
prepared according to the test methods set out in standards AS 2891.2.1 – 1995 and AS
2891.2.2 – 1995 (18, 19).

PERFORMANCE TESTING METHOD

Performance testing of the mixes were conducted using an Asphalt Mixture Performance
Testing (AMPT) machine (13), and the tests that were conducted included dynamic modulus
testing, Flow Number (FN) testing and overlay testing. The dynamic modulus, E*, is a
material property that is used to describe the viscoelastic behaviour of asphalt concrete
paving mixes, and it is a measure of the stiffness of an asphalt mix. Studies that have
investigated the accuracy of dynamic modulus of paving mixes have indicated that there is a
strong correlation between laboratory-observed dynamic modulus values and field-obtained
dynamic modulus values. The dynamic modulus tests in the reported study were conducted
according to the test method set out in AASHTO TP 79-09 (20). Each test that was conducted
in the AMPT machine required samples with specific dimensions and target air void volumes.
For the dynamic modulus test, moulds having a target air void volume of 7.0 ± 1.0% and
dimensions of 150 mm diameter and 175 mm height were prepared from each RAP mix and
from these moulds samples of 100 mm diameter and 150 mm height were cored. The
dynamic modulus test was conducted on three samples from each mix. During the dynamic
modulus test each test sample was subjected to continuous sinusoidal, stress-controlled
loading at frequencies of 10 Hz, 1 Hz and 0.1 Hz and at temperatures of 4°C, 20°C and 35°C,
and the applied stresses and the resulting strains were recorded by the AMPT machine during
the testing. The measured dynamic modulus values from the three samples of each mix were
used to determine the average dynamic modulus value for each mix, and the average dynamic modulus values of the mixes were compared using a t-test. The 95% confidence intervals (95% CI) were calculated for dynamic modulus values of each test mix, and the reported differences were significant at p-value < 0.005. The statistical analyses of the data were conducted using Statistical Package for the Social Sciences (SPSS) 2010 (21). Additionally, the recorded stress and strain measurements from the dynamic modulus tests were used to develop dynamic modulus master curve for test mix.

The flow number test is commonly conducted to assess the deformation (rutting) resistance of asphalt mixes. The results that are obtained by conducting FN tests in the laboratory have been found to have strong correlations to field rutting performance of asphalt paving mixes for various traffic levels, and FN has been utilised to assess and compare the rutting susceptibility of different asphalt mixes (15). In the presented study, the FN test was conducted to assess the rutting resistance of the RAP mixes in comparison to virgin HMA mixes. The FN tests were conducted according to the method set out in AASHTO TP 79-09 (20). The samples that were used to conduct FN tests had the same dimensions as the samples that were used for dynamic modulus testing, of 100 mm diameter and 150 mm height. The FN test was conducted at a temperature of 60°C, and during the test, a sample was subjected to a repeated axial stress of 600 kPa, where the sample was loaded for a period of 0.1 s followed by a rest time of 0.9 s. The resulting permanent axial strain for each load pulse was recorded in the AMPT software and these measurements were used to calculate the flow number of each RAP mix by determining the maximum number of cycles needed to reach the minimum axial strain rate (flow point). The flow number test was conducted on three replicate samples for each RAP mix, and the average number of FN test cycles of each mix was compared to the other mixes.

The overlay test is designed to measure the susceptibility of asphalt mixes to strain-controlled reflective cracking and this test was conducted as part of the presented study to compare the cracking susceptibility of RAP mixes to a virgin asphalt mix. The cracking estimations of the overlay test has been found to have close correlations to field performance of HMA mixes (14). The overlay tests were conducted according to the method set out in the standard Tex-248-F (17). Test moulds having dimensions of 150 mm diameter and 115 mm height were prepared for each RAP mix and samples having a thickness of 38 mm and length of 150 mm were cut from the moulds. The AMPT overlay test apparatus consisted of two steel plates with a joint between the plates, and a sample was attached to the two plates with epoxy, as shown in Figure 1. During the overlay test, one plate was held stationary while the other plate was pulled to open the joint to a maximum distance of 0.63 mm, and the plate was then pushed back to the original location. Each opening and closing motion was considered one cycle and the samples were subjected to cyclic loading in 10-second cycles. During each cycle the load required to move the plates to the specified displacement was recorded, and when the load was reduced by 93% percent of the first recorded load or when 1200 loading cycles were reached the test was automatically terminated. The overlay test was conducted at a temperature of 25°C and four samples were tested for each RAP mix. For each sample, the number of cycles to failure and the failure curve was recorded in the AMPT software and these results were compared between the mixes.
RESULTS

Dynamic Modulus Test Results

The results of the dynamic modulus testing are shown in Figure 2, which shows the average dynamic modulus values for each test mix at the three test temperatures. When comparing the dynamic modulus values of the three mixes, it can be seen that overall the 30% RAP mix has the highest average dynamic modulus of all the mixes, followed by the 15% RAP. The results showed that the addition of 30% of RAP to HMA notably increased the average dynamic modulus of the HMA mix at the lowest temperature of 4°C, where there was a statistically significant difference in the dynamic modulus values between the 30% RAP mix and the virgin HMA mix (p value = 0.001) at all three frequencies. The difference between the average dynamic modulus of the 30% RAP mix and the virgin HMA mix was also statistically significant (p value = 0.001) for all frequencies when the test temperature was 20°C. The higher modulus values of the RAP mixes in comparison to the virgin HMA mix indicated that the addition of RAP to HMA increased the stiffness of an HMA mix, which can be attributed to the aged material in the RAP. The results also indicated that the addition of higher quantities of RAP, such as 30% in comparison to 15%, further enhanced the stiffness increases of HMA that can be achieved by the inclusion of RAP. The presented dynamic modulus results agree with other published research (7), which have also found higher dynamic modulus values in HMA mixes incorporating RAP in comparison to virgin HMA mixes.
The dynamic modulus master curves for the three mixes are shown in Figure 3, and as can be seen, the mix containing 30% RAP had a higher dynamic modulus in comparison to the virgin HMA mix and the 15% RAP mix. The mix containing 15% RAP had the next higher modulus values, although the difference between the 15% RAP mix and the virgin HMA mix was not significant. The small difference in dynamic modulus values between the 15% RAP mix and the virgin HMA mix indicated that the addition of a smaller quantity of RAP to HMA does not have a significant impact on the stiffness behaviour of the resulting mix. At the higher frequencies (>10,000 Hz), there was no notable difference in the dynamic modulus values of the three mixes.

Note: * denotes a statistically significant difference between ‘HMA + 30% RAP’ mix and ‘virgin HMA’ mix

FIGURE 2 Dynamic modulus comparison of RAP mixes
Flow Number Test Results

Figure 4 shows the FN test results for the three mixes that were tested, where the three bars for each mix type shows the FN cycle that was reached in the three test replicates. When comparing the FN cycles, it can be seen that the samples from the 30% RAP mix reached the highest number of cycles, followed by the 15% RAP mix and finally the virgin HMA mix. The samples of the 30% RAP mix reached FN cycles of 230, 249 and 181, and there was a statistically significant difference between the FN cycles reached in 30% RAP samples and the samples from the virgin HMA mix (p value = 0.001). No significant difference was observed between FN cycles reached in the 15% RAP mix and the virgin HMA mix. When observing the variation in FN cycles of samples within mixes, it can be seen that in the 30% RAP mix there was a noticeable variation in the FN cycles between the three samples, although this variation was found to be not significant, where the coefficient of variance between the three replicates was 5.0% (shown in Table 1), which was within the acceptable variation limit for the FN test (<8.7%) (20). The variance of FN cycles within the samples of the virgin HMA mix was 6.4% and in the 15% RAP mix, the variance between the samples was 3.5%, which were also within acceptable variance limits and therefore the test results were satisfactory.

TABLE 1 Flow point and microstains of test mixes

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Flow point (cycles)</th>
<th>Microstrain at flow point (µε)</th>
<th>Coefficient of Variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin HMA</td>
<td>20</td>
<td>29796</td>
<td>6.4</td>
</tr>
<tr>
<td>HMA + 15% RAP</td>
<td>33</td>
<td>32042</td>
<td>3.5</td>
</tr>
<tr>
<td>HMA + 30% RAP</td>
<td>131</td>
<td>35004</td>
<td>5.0</td>
</tr>
</tbody>
</table>
During the FN test, the microstrains that were occurring within each sample was recorded by the AMPT machine, and these measurements were used to determine the flow point, which was the number of loading cycles corresponding to the minimum rate of change of axial strain within each sample, and the subsequent microstrain of the sample at flow point. The FN test measurements from the three samples of each mix were used to calculate the average microstrain of each mix, and these measurements are shown in Figure 5. The points at which flow occurred within each mix are shown in Table 1. When comparing the FN test results of the two RAP mixes to the virgin mix, it can be seen that there was a notable difference in the flow point measurements between the 30% RAP mix and the virgin mix, where in the 30% RAP mix flow occurred at 131 cycles while in the virgin mix flow occurred at 20 cycles. The difference in flow point measurements was not significant between the 15% RAP mix and the virgin mix, where flow point in the 15% RAP mix occurred at 33 cycles.

Previously published literature has indicated that higher flow numbers are associated with increased resistance to deformation, as well as that the addition of RAP increases the deformation resistance of HMA mixes (15, 16). When examining the results found from the FN test in the presented study, it can be seen that the presented results align with findings from earlier published studies. The presented FN test results indicated that the addition of 30% RAP to HMA increased the loading cycles needed to reach the flow point, which in turn indicated an increased deformation resistance of the modified HMA mix in comparison to a virgin HMA mix. The addition of 15% RAP to HMA did not notably increase the loading cycles at flow point of the HMA mix, which indicated that the deformation resistance improvements that can be achieved by the use of 15% RAP are not as significant as when 30% RAP was used.
Overlay Test Results

Overlay tests were conducted on the three mixes, where the number of loading cycles reached during the overlay test was used to assess the strain-controlled reflective cracking susceptibility of each mix. Generally, a higher number of loading cycles indicated increased resistance to cracking (7). Table 2 and Figure 6 show the results from the overlay tests and as can be seen, the overlay test cycles reached in the 15% RAP mix were similar to the virgin HMA mix, where in the 15% RAP mix all three samples reached close to 1200 loading cycles. In contrast, the samples from the 30% RAP mix reached significantly lower number of cycles in comparison to the other two mixes, reaching on average 413 loading cycles, which is approximately only 35% of the loading cycles reached by the virgin HMA mix. The variance of the number of loading cycles experienced by the test samples (shown in Table 2) were all below the limit of 30% specified for the overlay test (20) which indicated that the test results were statistically satisfactory.

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Average No. of Loading Cycles Reached</th>
<th>Coefficient of Variance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin HMA</td>
<td>1197</td>
<td>0.4</td>
</tr>
<tr>
<td>HMA + 15% RAP</td>
<td>1199</td>
<td>0.1</td>
</tr>
<tr>
<td>HMA + 30% RAP</td>
<td>413</td>
<td>6.7</td>
</tr>
</tbody>
</table>

FIGURE 5  Microstrain measurements for the test mixes
FIGURE 6 Number of loading cycles during overlay test

The trend in the reduction in tensile loads of test mixes during the overlay tests are shown in Figure 7. The trend in the tensile load reduction is similar between the virgin HMA mix and the 15% RAP mix, where the initial tensile load varied in the region of between 1.3 and 1.6 KN. In contrast, the 30% RAP mix had a higher initial tensile load of 2.7 KN, and there was a steep reduction in tensile load when compared to the other two mixes. The overlay test results clearly indicated that the addition of RAP, particular quantities of 30%, markedly increased the cracking susceptibility of an HMA mix, while interestingly, it was observed that the addition of 15% RAP to HMA did not have a significant increase on the cracking susceptibility of an HMA mix. This observation can be attributed to the proportion of aged material in the 30% RAP mix in comparison to the 15% RAP mix. In the 30% RAP mix there was a higher quantity of aged material than the 15% RAP mix and therefore the stiffness of the ‘HMA + 30% RAP’ mix was higher than the ‘HMA + 15% RAP’ mix, which would have increased its cracking susceptibility. This observed result was validated by findings from earlier published studies, where it has been found that lower quantities of RAP, such as 10% - 15%, had comparable cracking susceptibilities to virgin asphalt mixes, while the addition of higher quantities of RAP increased the likelihood of reflective cracking (3, 4, 6, 22).
Overall, the presented study results provide valuable understandings into RAP use in pavement surfacing practices, where it is common to find lower quantities of RAP, such as 10% - 15%, being used regularly in asphalt surfacing mixes (23). The reason for this practice is that in general, the mechanical performance of HMA mixes are not adversely affected by the use of small quantities of RAP, while concurrently the benefits of using RAP, particularly material savings and economic savings, can still be achieved. Additionally, when smaller quantities of RAP are used it prevents the need to provide extensive performance evaluations of the mixes to confirm satisfactory performance prior to the mix being used in practice. It is important to note that while there may be some adverse effects on HMA performance by the use of higher quantities of RAP, such as 30%, the material and economic savings that can be achieved by using RAP can be further increased when higher RAP quantities are used. Comparison of the results from the presented study to those results observed in the USA indicated that the obtained results aligned closely with findings from US studies (3, 11, 24). Hence, the presented study findings are valid and can be used to establish performance standards for RAP mixes in New Zealand.

### CONCLUSIONS

The presented study was conducted in order to investigate the effects the addition of various proportions of RAP material has on the performance of HMA mixes, particularly investigating the effect on the deformation resistance and cracking resistance of HMA mixes. The test methodology of the study included conducting dynamic modulus tests, flow number tests and overlay tests using an AMPT machine. This paper presents the initial results of a study that is being conducted to establish performance limits for RAP use in New Zealand’s pavement surfacing practices.
From the testing it was observed that the addition of RAP, particularly 30% RAP, significantly enhanced the dynamic modulus (stiffness) and deformation resistance of an HMA mix. The addition of 15% of RAP also increased the dynamic modulus of virgin HMA, although this increase was lower than when 30% of RAP was added. The effect on the deformation resistance of virgin HMA was limited when 15% of RAP was added, where no significant variation in flow number test results were observed between the 15% RAP mix and the virgin HMA mix. When considering the reflective cracking susceptibility of RAP, it was observed that the addition of RAP, particularly 30% had a notable reduction in the cracking resistance of an HMA mix, achieving only 35% of the cracking resistance of a comparable virgin HMA mix. In contrast, the addition of 15% of RAP to HMA had similar cracking resistance properties of a virgin HMA mix. Overall, the findings of the presented study provided valuable understandings in to the performance of RAP material, particularly the effect different RAP proportions has on the mechanical performance of an HMA mix. The study results can be used as a starting point for validating the performance benefits that can be achieved by using RAP in asphalt pavement construction.

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REFERENCES


11. NCHRP. Incorporation of Reclaimed Asphalt Pavement in the Superpave System. NCHRP 09-12.


