RAP REJUVENATION – EFFECTS ON THE DEFORMATION AND CRACKING PERFORMANCE

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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. This study investigated the performance of RAP mixes containing rejuvenation additives in order to determine the effects of those additives on the deformation (rutting) resistance, cracking resistance and fatigue performance of RAP mixes. Laboratory testing was conducted on 11 RAP mixes that were manufactured using RAP proportions of 15% and 30%, as well as with the addition of different types of rejuvenating agents.

The results produced useful performance indicators for the use of rejuvenation additives in RAP. The mixes that had rejuvenation additives preserved the high deformation resistance of RAP mixes, particularly at the higher RAP proportion of 30% when compared to a mix with no RAP, and concurrently the addition of rejuvenators counteracted against over-stiffening effects of RAP. The addition of RAP, especially 30% RAP proportion, had poorer fatigue performance than when only 15% RAP, but with the use of rejuvenation agents, the fatigue performance of the high RAP mixes was improved significantly. The use of oil for RAP rejuvenation had marginally better fatigue performance than a chemical rejuvenation agent. The research results provided a valuable understanding of the behaviour of RAP mixes, and in particular the positive performance results that can be gained by using rejuvenation additives.

Key words: RAP, recycling, asphalt, pavements, rejuvenation, dynamic modulus

INTRODUCTION

Recycled Asphalt Pavements (RAP) are a sustainable paving method that has many advantages to the pavement industry. The production process for recycled pavement material consists of milling and recovery of existing asphalt pavement layers during pavement rehabilitations, and this recovered material is then combined with new bituminous binder and aggregates to produce recycled material that is suitable for use in asphalt pavement construction. The use of RAP as an alternative to purely 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) up to 99% of reclaimed asphalt is recycled as pavement material (National Asphalt Pavement Association, 2013). In Australia approximately 6% of reclaimed asphalt is being used to produce RAP mixes (Australian Asphalt Pavement Association, 2013). In New Zealand, RAP has been utilized in pavement construction for several years. Presently, the allowable proportion of reclaimed material in a RAP mix is between 15% - 30%, however, the practical use of RAP is still limited to around 15% (NZ Transport Agency, 2010). 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 (Lo Presti et al., 2012). The need for approval to use higher quantities of reclaimed material can limit the widespread use of higher quantities of reclaimed material. Recent published research has shown that the use of RAP, even at smaller proportions of 15%, can return improved performance outcomes, with RAP inclusion providing better deformation resistance to wholly virgin HMA mixes (Kodippily et al., 2014).

One of the shortfalls of RAP mixes that comes hand in hand with the increased stiffness is the lowered resistance to cracking. Particularly in the case of strain-controlled reflective cracking, RAP mixes can be more prone to cracking than non-RAP mixes. To overcome this shortfall, alternative binder forms such as polymer modified binder has been used in RAP mixes (Kodippily et al., 2015). Apart from polymer binder modification, the use of additives can also aid with improving the mechanical performance of RAP mixes. The use of rejuvenation additives is one of the ways in which HMA mixes can be modified, although this is an area of research that is not well explored particularly when RAP is used (Tran et al., 2012). Hence, the effects of RAP binder rejuvenation needs to be investigated, as this new rejuvenated RAP mixes has the potential to further increase the performance benefits that are often gained by using RAP.

Field analysis of RAP use has confirmed the improved mix performance that RAP can provide, and it is expected that these benefits can be further increased if higher quantities of RAP are used. In order to promote RAP the use of higher RAP quantities particularly in the New Zealand context, there is a need to establish performance limits for RAP mixes, such that it can encourage the use of high RAP quantities in paving practices.

OBJECTIVES AND SCOPE

The objectives of this study were to investigate the performance benefits of RAP rejuvenation additives. Specifically, the study aimed to characterise the rutting performance, strain-controlled cracking performance and fatigue performance RAP mixes containing rejuvenation additives. The results that were assessed in this study were based on testing of laboratory-manufactured RAP samples, and the RAP proportions that were tested were selected based on typical RAP quantities that are used in asphalt mixes in New Zealand. It was intended that the testing methodology that is presented in this study would form the benchmark for performance testing of RAP mixes and RAP rejuvenation in New Zealand.

REJUVENATION ADDITIVES IN HMA MIXES

The inclusion of recycled paving material in the production of HMA paving mixes alters its characteristics, specifically, the deformation performance and cracking performance of HMA. By its nature, RAP is old material and the binder that is present in RAP is aged and stiffer, hence the inclusion of this aged binder in to virgin HMA material results in a modified mix that has the potential to be stiffer. The increased stiffness provided by RAP has its benefits, particularly when considering the rutting 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 (Pereira et al., 2004, Kodippily et al., 2014, Li et al., 2008). 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 rutting resistance became more noticeable (Mogawer et al., 2011). The increased stiffness provided by RAP is extremely beneficial as it delivers the necessary stiffness requirements for pavement layers while at the same time minimising the need for good-quality pavement aggregates. However, with this high stiffness, the RAP mixes may also be more prone to cracking. Modifications, in the form of polymer modified binder, can be used to achieve softer binder in RAP, although mixed results have been observed in previous studies (Holleran et al., 2013, Kodippily et al., 2015, Casey, 2003).

The addition of rejuvenation additive to RAP mixes has the potential to increase the binder viscosity and overcome the stiffening effects of the old binder in RAP. Rejuvenating agents can be added to recovered binder from RAP, and this can recover some of the properties of old binder. There are blending charts that are available that provides guidance on the quantities of rejuvenation additives that can be added to recycled mixes to achieve specific performance. The use of rejuvenation agents in RAP mixes was investigated by Shen et al. (2007), where the properties of RAP mixes containing softer binder were compared to RAP mixes containing rejuvenators. The authors noted that the mixes that contained rejuvenators had similar or better performance properties, such as rutting, when compared to mixes that had softer binder, and an added benefit of rejuvenator inclusion was that more RAP could be incorporated into the mixes when rejuvenators were used. Similar performance results were also reported by Zaumanis et al. (2013) where different types of oil-based and engineered rejuvenators were tested on recycled mixes containing 40%-100% RAP contents. It was reported that the rejuvenators were able to increase the low-temperature creep compliance of the RAP mixes, while at the same time increasing the indirect tensile strength and thereby improving the low-temperature cracking performance.

A practical aspect that concerns the addition of rejuvenating agents is the degree of mixing that takes place between the aged RAP binder and the rejuvenating agents. In their study, Carpenter and Wolosick (1980) noted that only partial blending takes place between rejuvenators and RAP immediately after mixing, although overtime the additives would diffuse into the ages RAP binder film and result in better blending. In the study by Kadar (1996) it was suggested that the rejuvenation process develops over a long time, where blending may take place over 3-6 months. Hence, the true potential of RAP rejuvenation may only be seen in the long term.

MIX DESIGN METHOD

Performance testing was conducted on 11 asphalt mixes containing various proportions of RAP and rejuvenation additives. Table 1 shows the design properties of the mixes, and Table 2 shows the volumetric properties of the mixes. The two rejuvenating additives that were used in the study were Otech oil and Evoflex CA additive.

Table 1 Design properties of the mixes

Mix ID	Mix Name	Binder type	Aggregate	Binder Additive	Binder Additive (%)	Binder content (%)	RAP content (%)
1	Virgin HMA	PGT64	AC14	N/A	0	5.3	0
2	15%RAP	PGT64	AC14	N/A	0	5.4	15
3	30%RAP	PGT64	AC14	N/A	0	5.0	30
4	30%RAP + Oil	PGT64	AC14	Otech Oil	1.0	5.0	30
5	30%RAP (0.2% extra binder)	PGT64	AC14	N/A	0	5.2	30
6	30%RAP (0.4% extra binder)	PGT64	AC14	N/A	0	5.4	30
7	30%RAP (AC10)	PGT64	AC10	N/A	0	5.7	30
8	30%RAP (AC10 + 1.5%Additive)	PGT64	AC10	Evoflex CA	1.5	5.7	30
9	30%RAP +1.5%Additive)	PGT64	AC14	Evoflex CA	1.5	5.0	30
10	30%RAP (AC10 + 1.5%Additive + Extra conditioning)	PGT64	AC10	Evoflex CA	1.5	5.7	30
11	30%RAP (AC10 + 2%Additive)	PGT64	AC10	Evoflex CA	2.0	5.7	30

Table 2 Volumetric properties of the mixes

Mix ID	Voids in Mineral Aggregate (VMA)	Voids Filled with Asphalt (VFA)	Air voids (%)
1	17.9	60.4	7.1
2	17.4	60.8	6.8
3	16.7	61.1	6.5
4	17.0	61.6	6.5
5	17.7	57.6	7.5
6	17.8	59.8	7.2
7	18.6	59.7	7.5
8	18.9	63.2	7.0
9	16.8	60.3	6.7
10	18.9	63.2	6.9

11	18.8	63.3	6.9

The mix design process of the test mixes were conducted according to the specifications set out in NZTA M/10:2010 (NZ Transport Agency, 2010). The NZTA M/10:2010 provides specific mix envelopes for asphaltic concrete and thin surfacing mixes to which the particle size distribution of the test job mix formula must comply. As part of the specifications, the effective binder content for the mix requires to be between 5.0% -7.0%. The bitumen that is used in the asphaltic concrete mixture is required to be 80/100 or 60/70 penetration grade.

In accordance with NZTA M/10:2010, RAP was added during the mixing process. The quality of the RAP material is also required to comply with the mix design volumetric requirements of standard AC materials. 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 11 mixes were prepared according to the test methods set out in standards AS 2891.2.1 – 1995 and AS 2891.2.2 – 1995 (Standards Australia, 1995b, Standards Australia, 1995a). Figure 1 shows the aggregate grading of the mixes and RAP aggregates that were used for the test mixes.

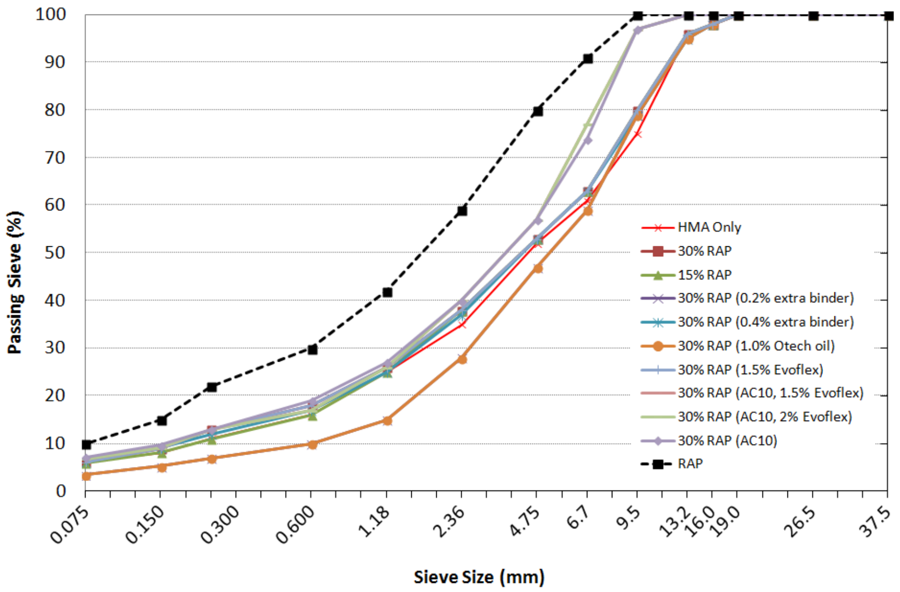

Figure 1 Aggregate grading curves and RAP grading curve

PERFORMANCE TESTING METHOD

Modulus / Stiffness Testing

Performance testing of the mixes was conducted using an Asphalt Mixture Performance Testing (AMPT) machine (Federal Highway Administration, 2013), and the tests that were conducted included dynamic modulus, flow number, overlay and fatigue tests. The dynamic modulus tests were conducted for each RAP mix conducted according to the test method set out in AASHTO TP 79-09 (AASHTO, 2009). Three replicates of cores were prepared to a target air void volume of 7.0 ± 1.0%, and test samples having dimensions of 100 mm diameter and 150 mm height were drilled and sawn from the cores. Each sample was subjected to continuous sinusoidal, stress-controlled loading at frequencies of 10 Hz, 1 Hz and 0.1 Hz at temperatures of 4°C and 20°C, and 10Hz, 1Hz, 0.1Hz and 0.01Hz at a temperature of 35°C. The applied stresses and the resulting strains were recorded during the testing, and the recorded modulus values were used to determine the average dynamic modulus value for each mix. The recorded stress and strain measurements from the dynamic modulus tests were used to develop dynamic modulus master curve for the test mixes.

Deformation Resistance Testing using Flow Number Test

The flow number test is commonly conducted to assess the deformation (rutting) resistance of asphalt mixes. The flow number tests were conducted according to the method set out in AASHTO TP 79-09 (AASHTO, 2009). The cores for the flow number tests were prepared similarly to dynamic modulus samples, having dimensions of 100 mm diameter and 150 mm height. The flow number test was conducted at a temperature of 60°C. Each sample was subjected to a repeated axial stress of 600 kPa, with a loading period of 0.1s followed by a rest period of 0.9s. The resulting permanent axial strain for each load pulse was recorded. The test outputs were then used to determine the flow time (flow point) of the mix, which defines the point at which shear deformation occurs. The number of loading cycles at flow time gives the flow number for a mix. The flow number test was conducted on three replicate samples for each test mix, and the average flow number test cycles of each mix was compared to the other mixes.

Strain-Controlled Cracking Resistance of RAP 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 containing rejuvenators. The overlay tests were conducted according to the method set out in the standard Tex-248-F (TxDOT, 2013). Samples having a thickness of 38 mm and length of 150 mm were used for the overlay tests.

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. 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 mix. For each sample, the number of cycles to failure and the failure curve were recorded in the AMPT software and these results were compared between the mixes.

Fatigue testing and Prediction of RAP mixes

Uniaxial fatigue testing, also known as the Simplified Viscoelastic Continuum Damage test (S-VECD), was conducted on the RAP mixes using the AMPT uniaxial fatigue kit. The outputs of the fatigue test results were combined with linear viscoelastic characteristics of the mixes found from dynamic modulus tests to conduct fatigue predictions for the test mixes. The fatigue tests and fatigue life predictions were conducted according to the methodology set out in (Hou et al., 2010). For the AMPT fatigue tests, samples were prepared having dimensions of 100 mm diameter and 150 mm height. Two metal platens were glued to the top and bottom of each sample using steel epoxy, and the specimen was bolted into the fatigue testing frame. LVDTs then attached to the specimen. The fatigue test was conducted at a temperature of 20°C. During the fatigue test, the dynamic modulus and phase angle of the mix was recorded, and the point at which the phase angle peaked and dropped was considered the point of failure of the specimen. For each mix, three specimens were tested at three microstrain levels such that the samples failed at different loading cycles. Using the outputs of the fatigue test, fatigue life predictions were made for each RAP mix.

RESULTS

Stiffness Performance of RAP Mixes with Rejuvenation Additives

The dynamic modulus master curves for the test mixes comparing the effects of rejuvenators are shown in Figure 2. As can be seen, the addition of 30% RAP had a notable increase in the stiffness when compared to the control mix. The use of 15% RAP also increased the stiffness, however, this is only marginal. The addition of rejuvenators into the 30% RAP mix had lower stiffness performance than only 30% RAP, however it was still notably better than the 15% RAP mix and the control mix. It is likely that the lower stiffness created by rejuvenators will reduce fatigue cracking resulting from overly-stiff RAP mixes.

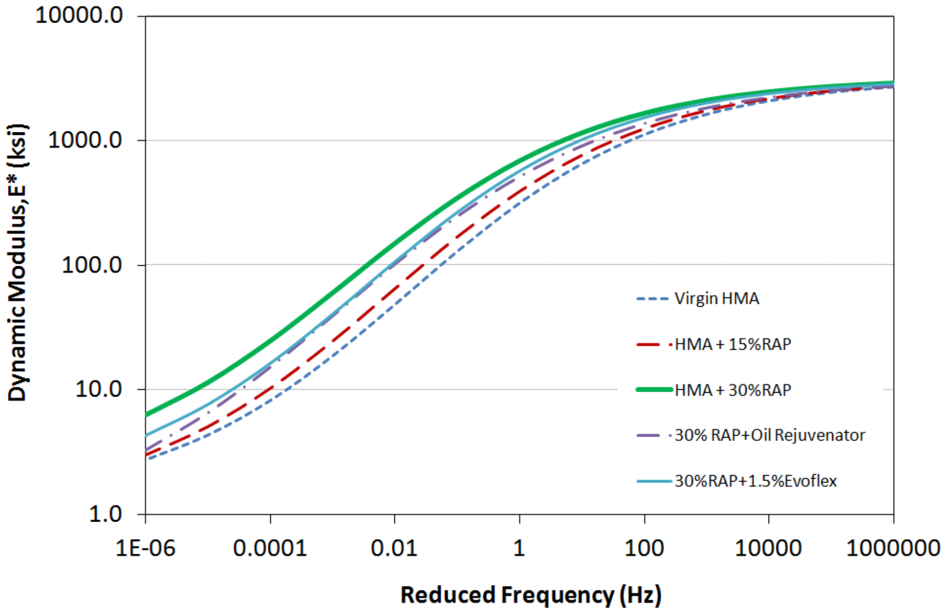

Figure 2 Dynamic modulus master curves comparison between RAP and rejuvenation mixes

Figure 3 shows the master curve comparison between RAP rejuvenators and the use of varying binder quantities and aggregate gradings. The addition of higher binder quantity had a similar modulus result as when rejuvenation agents were used. This result was promising as it indicated that the use of rejuvenators can achieve similar RAP mix performance without the need for higher quantities of binder.

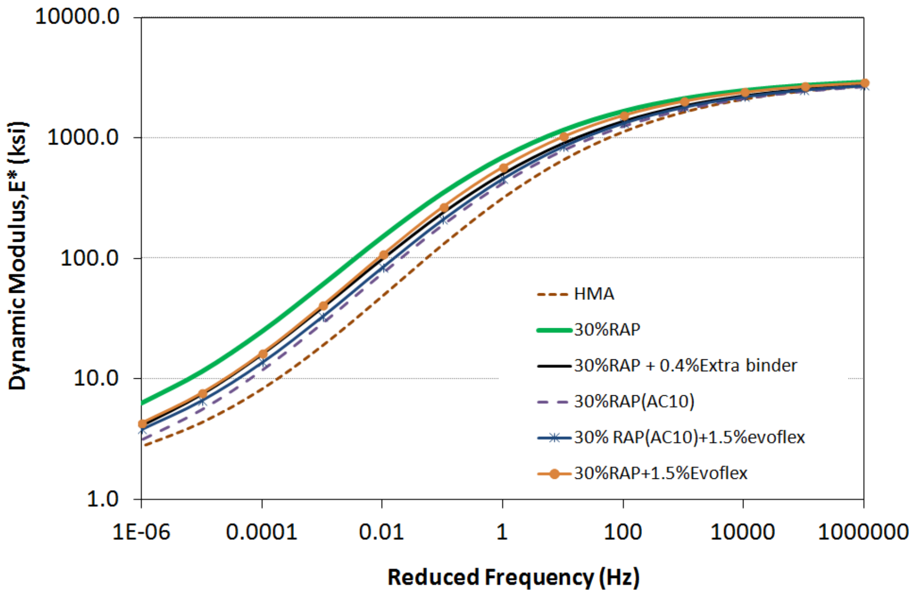

Figure 3 Dynamic modulus master curve comparison between RAP rejuvenators vs varying binder quantities

The results of the dynamic modulus testing are shown in Figure 4, which shows the average dynamic modulus values for the rejuvenated mixes at test temperatures of 4°C, 20°C and 35°C. At the low temperature of 4°C, the 30%RAP mix has the highest modulus followed by oil rejuvenator mix and then Evoflex added mix. This pattern changes at 20°C when Evoflex mix has a higher modulus than the Otech oil rejuvenated mix. This difference in moduli values for Otech oil and Evoflex rejuvenators shows that different performances can be expected from these two rejuvenators at different temperatures. Evoflex may give better RAP performance at high temperatures while Otech oil may be more suited to low temperature RAP performance.

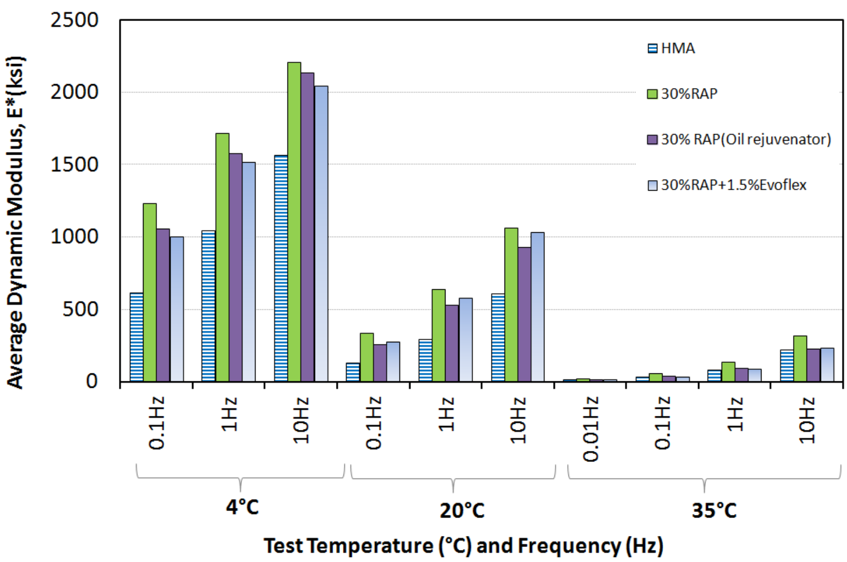

Figure 4 Average dynamic modulus results – RAP vs Rejuvenators

Figure 5 shows the average dynamic modulus values of RAP mixes with extra binder and a finer grading. It is clear that the addition of extra binder does not achieve the same high modulus as when only 30% RAP is used or when Otech oil rejuvenator is present. The mix with finer grading has even lower modulus values than the mix with extra 0.4% binder. The lower modulus of these mixes may be ideal for preventing excessive stiffness of RAP mixes, but further analysis is needed to examine how this reduced modulus affects the cracking performance of the mixes.

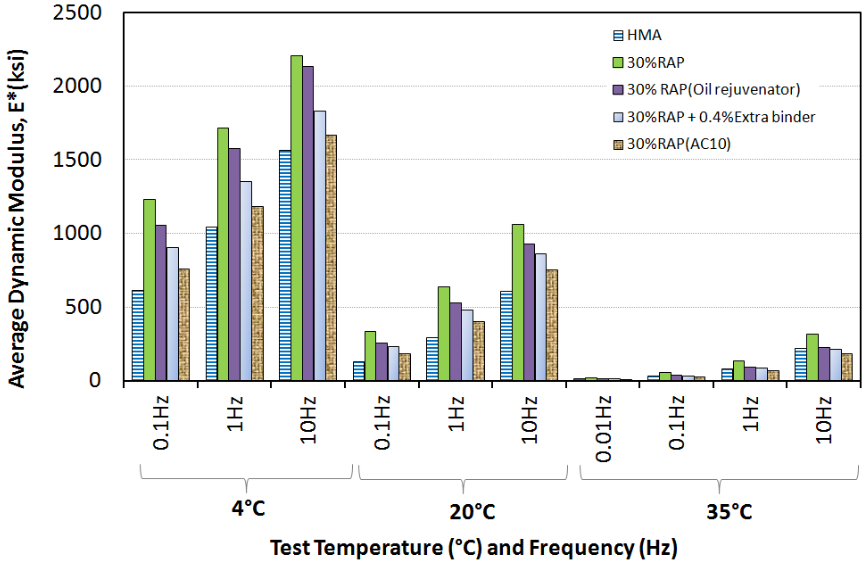

Figure 5 Average dynamic modulus results – Rejuvenators vs Extra binder and grading

Deformation Performance of the RAP and Rejuvenator Mixes

The flow number tests were conducted on the RAP mixes to investigate the rutting resistance of the mixes. The results from five mixes are shown in Figure 6, which indicates the flow point of each mix. The flow point is commonly known to as the point at which tertiary flow occurs in a mix, specifically the point at which the mix deforms or ruts (Rodenzo et al., 2010). The flow point refers to the number of loading cycles corresponding to the minimum rate of change of axial strain within each sample, and the subsequent microstain of the sample at flow point.

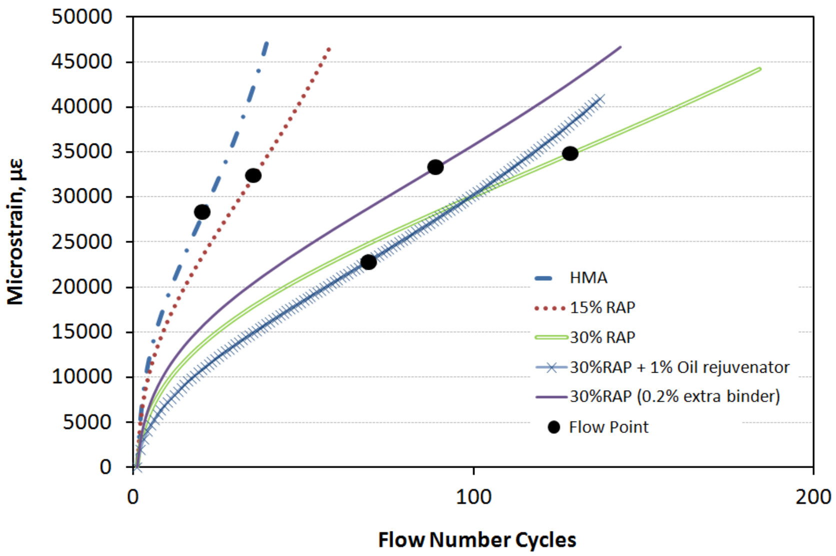

Figure 6 Flow number test results showing flow point

There are notable differences in flow behaviour between the mixes. The 30% RAP mix has the highest resistance to deformation, with the flow point occurring at 131 cycles at a microstrain of 35000. Surprisingly, the Otech oil rejuvenator mix had noticeable lower resistance to deformation than the 30% RAP mix, reaching its flow point at low microstrain value of 22600 and at 67 cycles. The 30% RAP mix with higher binder performed better than the rejuvenated mix, with the flow point of this mix occurring at 33000 microstrain and 92 cycles. When looking at the flow number test behaviour of the rejuvenator mix, it is clear that there is an increase in microtrain reached by the mix as the test progresses. This indicates that some hardening may occur in the mix over continuous loading, and reach similar performance limits as the higher binder mix.

In order to make further comparisons between the rejuvenated mix and the high binder mix, the flow number test cycles were plotted in Figure 7. This figure shows the number of cycles reached by each test sample until a microstrain of 50000 was reached. Interestingly, the flow cycles reached are very similar between the Otech oil rejuvenator mix samples and the high binder mix samples. Due to the unavailability of flow number test results from other mixes, it was not possible to investigate the effect that a finer grading or Evoflex additive may have made to rejuvenated RAP mixes.

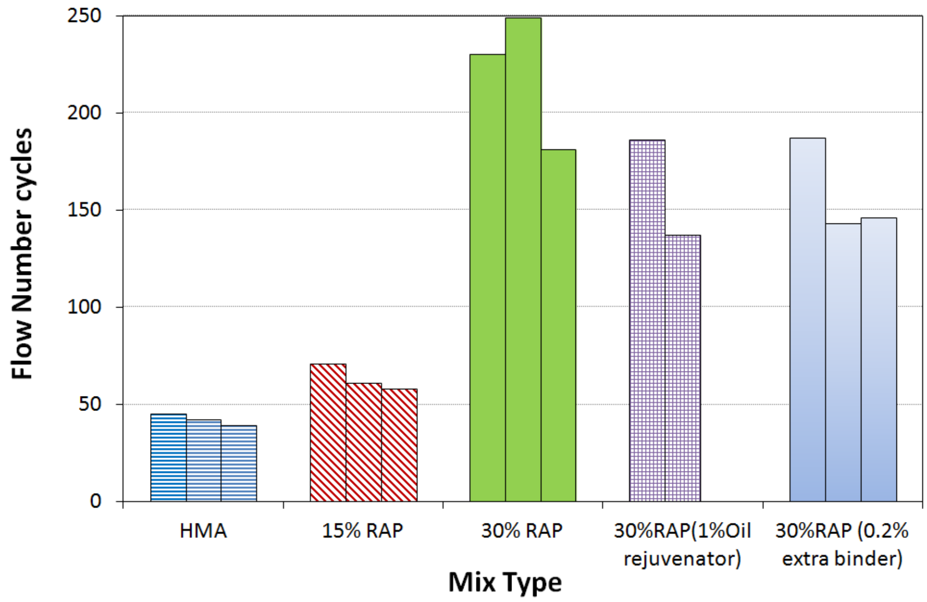

Figure 7 Flow number test cycles

Reflective Cracking Resistance of Rejuvenated RAP Mixes

Overlay tests were conducted on the RAP mixes to determine their strain-controlled cracking resistance, and the results are shown in Figure 8. As can be seen, the cracking resistance of mixes that have RAP isn't as high as the HMA only mix, reaching only about 400 loading cycles (shown in Figure 10), but this can be expected given the aged binder in RAP making the mixes stiffer. The addition of rejuvenation agents to an AC10 grading mix can significantly improve the cracking performance of the RAP mixes, and this mix reached on average 1019 loading cycles (Figure 10). Generally, a higher number of loading cycles indicates increased resistance to cracking, and the behaviour of the rejuvenator in the AC10 mix indicates extremely good cracking resistance. It is interesting to note that the use of rejuvenators in the AC14 grading mix has not achieved a better cracking resistance. This is somewhat unexpected, as the intention of adding rejuvenating agents was to rejuvenate the aged RAP binder and allow for better performance. It is quite likely that the higher quantity of binder that was in the AC10 mix (5.7% in AC10 mix compared to 5.0% in AC14 mix) may be positively affecting the performance of the rejuvenators. Further investigations are needed to establish how the addition of extra binder along with rejuvenator additives may affect the cracking performance of AC14 mixes. Additionally, using rejuvenators in a RAP mix as an additive may not be necessarily rejuvenating the RAP binder well. A better way to incorporate these additives may be to remove the binder from RAP and then rejuvenating it before adding it back into the mix. This method of binder rejuvenation is more likely to allow better mixing between the additives and aged RAP binder, thus achieving the full benefits of the rejuvenator additives.

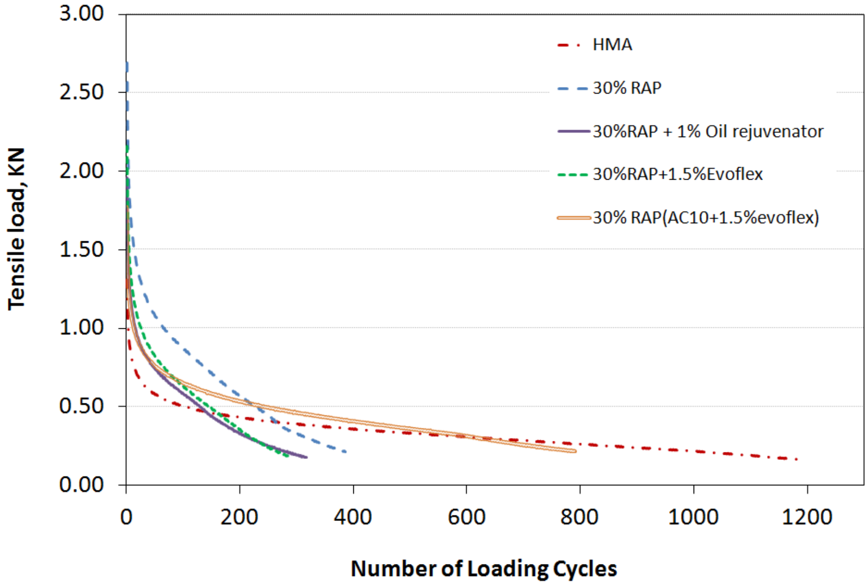

Figure 8 Overlay test results RAP vs Rejuvenators

Figure 9 shows the cracking performance of RAP mixes with the addition of extra rejuvenator addition and finer AC10 grading. The use of a finer grading improved the performance of RAP mixes. It is interesting to note that the use of higher quantity of rejuvenation additive, ie 2% Evoflex, did not provide any better cracking performance than when only 1.5% Evoflex was used. Again, this may be due to rejuvenators not having the intended effect because of inadequate mixing between RAP and the rejuvenator additives. This result also indicates that there may be an optimal quantity of rejuvenator additive that can be used for RAP mixes.

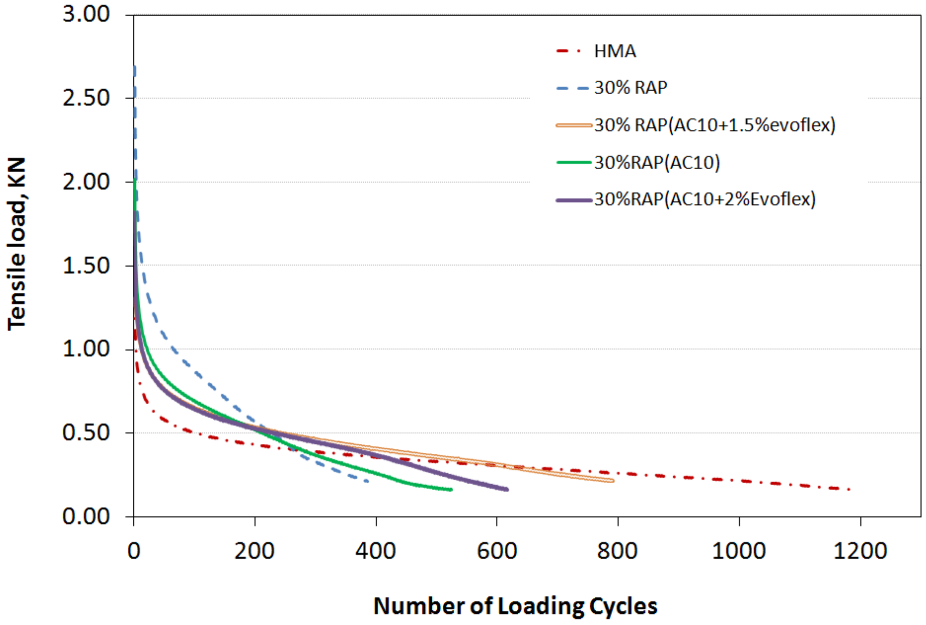

Figure 9 Overlay test results – the effects of extra binder and finer aggregate grading

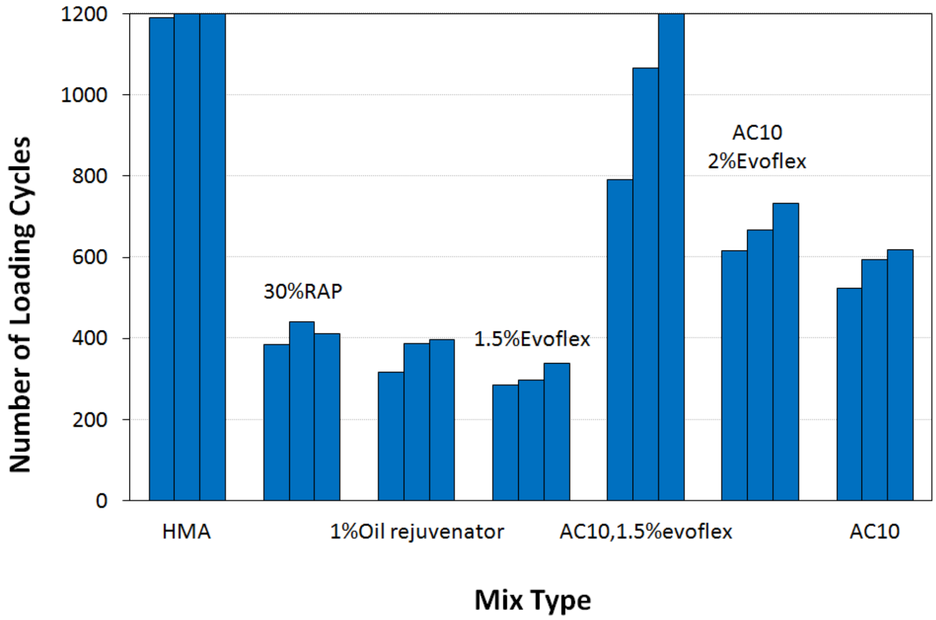

Figure 10 Number of overlay loading cycles for each mix

Fatigue Performance of Rejuvenated RAP Mixes

The fatigue performances of rejuvenated RAP mixes are shown in Figure 11. Most notable of these results is the 30% RAP mix, which has the poorest fatigue performance. This is expected as the dynamic modulus testing indicated the 30% RAP mix to be the stiffest mix.

The addition of rejuvenators, particularly Otech oil, significantly improved the fatigue performance of the RAP mix, even more than the 15% RAP mix.

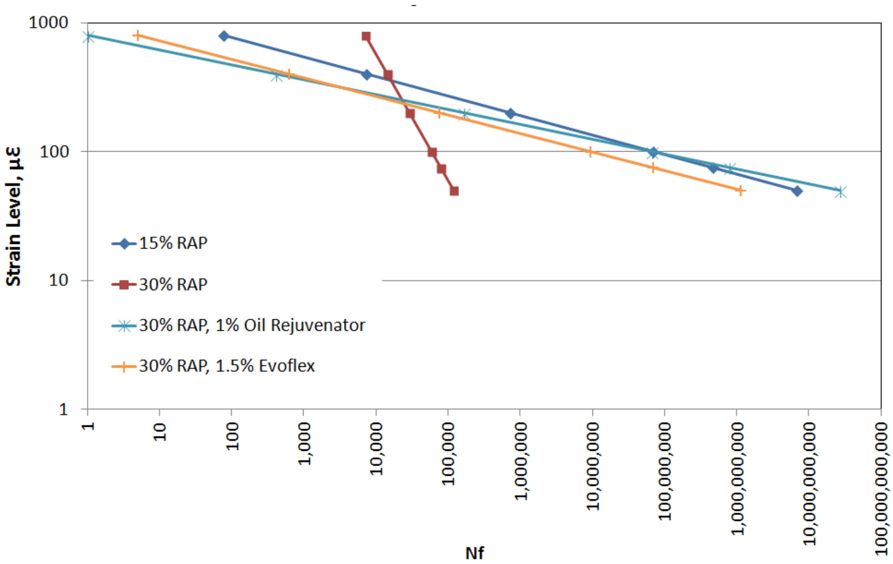

Figure 11 Fatigue predictions for rejuvenated RAP mixes

The fatigue performance predictions for RAP mixes containing extra binder and AC10 grading are shown in Figure 12. As expected, the RAP mix containing AC10 grading has the best fatigue performance. The addition of extra binder did not vastly improve the fatigue performance of RAP mixes.

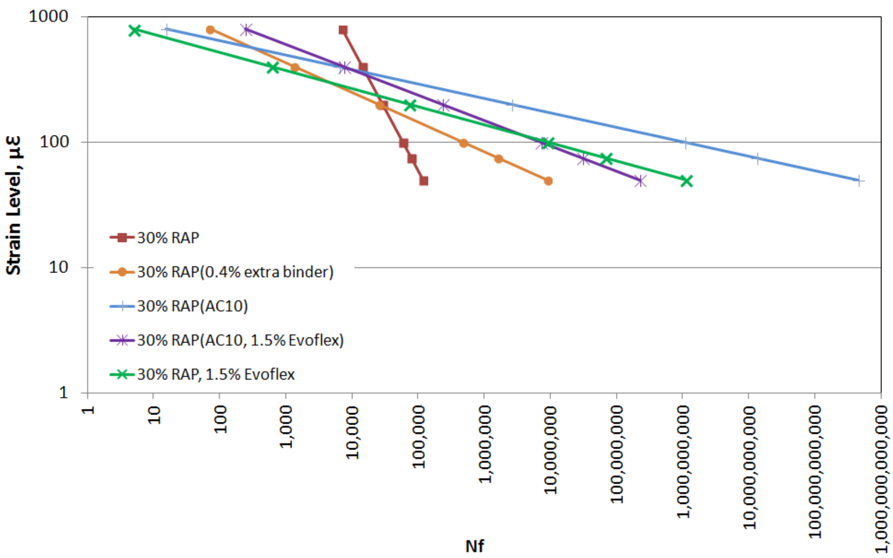

Figure 12 Fatigue performance of RAP mixes containing extra binder and finer grading

Shown in Figure 13 are the fatigue cycle predictions for each mix at varying microstrain levels. This figure clearly shows the differences in fatigue performance that can be expected from RAP mixes. The 30% RAP mix has the poorest fatigue performance, particularly at low microstrains, reaching only 100,000 fatigue cycles. The use of Otech oil clearly improves the fatigue performance, especially at the low microstrains of 50με and 75με. The addition of Evoflex rejuvenating additive also has similar fatigue improvements at low microstrains, although the fatigue cycles that can be achieved with Otech oil is a magnitude higher. The performance of both of these rejuvenating additives shows how beneficial they are to improving fatigue characteristic of RAP that had otherwise offset its good deformation performances. Additionally, it is positive to observe that the low microstrain fatigue performance of the Otech oil mix is similar to the 15% RAP mix. This result, along with the observations of dynamic modulus and flow number test results show that by using rejuvenating agents, the RAP quantity can easily be increased without compromising mix performance.

It is interesting to note that the grading had a significant effect on the fatigue performance of RAP mixes, where AC10 grading achieved notably higher fatigue cycles than the AC14 mix. However, when rejuvenating additives were used, the performance of these mixes became similar. At high microstrains, Evoflex rejuvenator made no difference to fatigue performance of the AC10 mix.

At the very high microstrain level, it appears the rejuvenators do not improve fatigue performance of RAP mixes. But that can be overlooked given the excellent fatigue performance at low microstrains, which suggests these rejuvenated mixes will have higher endurance fatigue limits than RAP-only mixes.

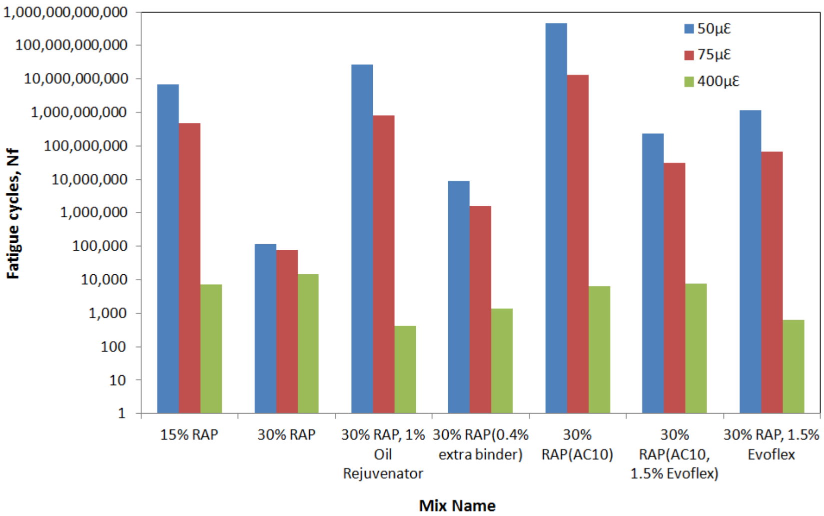

Figure 13 Fatigue cycles reached at varying microstrain levels

Directions for Further Investigations into RAP Rejuvenation

The outcomes of the presented test results indicate significant performance improvements to RAP mixes by the use of rejuvenating additives. In the presented investigations rejuvenating additives were added to the new binder prior to mixing it in with the RAP. Alternative methods of adding rejuvenating agents can be further investigated, particularly the effect that rejuvenators would have on aged binder extracted from the RAP material. Mixing rejuvenating agents with extracted binder and then re-introducing it to a RAP mix can allow for better mixing between the binder and the additives, leading to better binder rejuvenation, and possibly further improvements to the performance of RAP mixes. Previous research has indicated that the RAP quantity can affect the extent of binder blending that takes place between new binder and aged RAP binder (NCHRP, 2000). Therefore, there is a need to further investigate the technique behind RAP binder rejuvenation.

The benefit that RAP rejuvenation has over alternatives, such as the use of higher binder, is that they allow high quantities of RAP to be used without offsetting its performance properties such as fatigue performance and cracking performance. Moving forward, there is a need to test the effect of the rejuvenating additives in the field, particularly the fatigue performance of the RAP mixes.

CONCLUSIONS

The presented study was conducted to investigate the performance of RAP mixes that contained rejuvenating additives, particularly to investigate the rutting, cracking and fatigue performance of rejuvenated RAP mixes. Mixes containing 15% RAP, 30% RAP, two different additives, namely Otech oil and Evoflex rejuvenating agent, and a mix with a finer grading were tested. The test methodology included conducting dynamic modulus, flow number, overlay and fatigue tests using an AMPT machine.

The results showed significant performance improvements to RAP mixes when rejuvenating additives were used. As expected, the 30% RAP mix, with and without rejuvenators, had notably higher modulus and better rutting resistance than the 15% RAP mix and the control mix with no RAP. In terms of cracking resistance, the rejuvenating agents did not have a significant improvement to the cracking performance of 30% RAP mix. Although, when a smaller aggregate grading was used for the RAP mix, the rejuvenating agents had a notable improvement on the cracking resistance.

The most notable effect of rejuvenating additives was seen on the fatigue performance of RAP mixes. The 30% RAP mix that had Otech oil as a rejuvenator had extremely good fatigue performance when compared to the 30% RAP mix without additives. In fact, the fatigue performance of this rejuvenated RAP mix was similar to the 15% RAP-only mix, which showed how using rejuvenating agents can allow the use of higher RAP quantities without compromising the mix performance.

Overall, the findings of this study provided valuable insight in to the performance of RAP mixes, particularly with the use of rejuvenating additives, and showed that rejuvenating agents can have many performance benefits. The study also highlighted the need for field performance testing of these rejuvenated RAP mixes, which is essential for confirming the test findings.

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