Turning RAP into a value added pavement asset

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Summary
The incorporation of reclaimed asphalt pavement (RAP) into new asphalt provides the industry with an opportunity to help conserve our scare non-renewable raw materials. However economics remains the key driver for asphalt manufacturers to incorporate increasing percentages of RAP in their mixes. Notwithstanding the latter they have to overcome some major challenges in order to increase the use of RAP above 15% to ensure adequate asphalt performance in the longer term.

Client specifications limit the amount of RAP that can be used in asphalt, however there are also some major obstacles that an asphalt manufacturer has to overcome which include inter alia plant capability, mix type and application, RAP availability and quality. This paper will describe the journey under taken by Boral Asphalt to manufacture asphalt with up to 30% RAP using a double drum plant in Sydney without compromising the performance of the final product.

Key to the successful use of RAP was the development of special procedures for the procurement, handling and processing of the RAP to ensure a consistent end product for use in asphalt. The ongoing monitoring of the key variables of the processed RAP is very critical to ensure uniform quality of the asphalt. The amount and properties of the aged binder in the RAP was measured along with the moisture content and the gradation of the various RAP fractions.

A detailed test program was developed to manufacture and lay trial mixes of AC14 heavy duty asphalt wearing course using various percentages of RAP. Extensive laboratory tests were undertaken to measure the fatigue, rut resistance and resilient modulus of the plant produced mixes with increasing percentages of RAP for different mixes. The recovered binder of the recycled asphalt mixes was monitored to compare the change in viscosity at different RAP percentages. In-situ cores were taken from the pavement immediately after placement and two years later for moisture sensitivity testing.

The paper demonstrates that RAP is a valuable engineering material which offers economic benefits to both the asphalt manufacturer and road authority without compromising the performance of the asphalt. Furthermore the increased use of RAP will help reduce the energy consumption and green house gas emissions generated during the production of hot mix asphalt. The key findings from the recent AAPA study tour to the USA on the usage and performance of RAP will also be reported on. Both sets of findings will help dispel any misconceptions that asphalt containing RAP is inferior to mix manufactured from only virgin raw materials.

1. Introduction

The incorporation of reclaimed asphalt pavement (RAP) into new asphalt provides the industry with an opportunity to help conserve our scare non-renewable raw materials namely bitumen and mineral aggregates. Further, more asphalt producers are also driven by the economic incentive that can be realised by reducing their demand for new bitumen and aggregates which helps offset the cost of additional handling required to process the RAP into a usable raw material. The combination of the sustainable and economic benefits should be key drivers for the Industry wanting to maximise the use of RAP to ensure that asphalt remains a competitive pavement material into the future.

Notwithstanding the above benefits most road asset owners and their engineers are generally reluctant to use high percentages of RAP in asphalt. This fact is supported by the restrictions placed on the use of RAP in asphalt by the state road authorities in Australia. Table 1 below shows a summary of the permissible amount of RAP allowed in asphalt specifications.

Table 1: maximum % RAP allowed in State Road Authority specification

State	Layer	max RAP	Conditions
WA	Wearing course	Nil	
	Intermediate & base course	Nil	Considering allowing 15% in non surface
QLD	Wearing course	Nil	
	Intermediate & base course	15%	Bitumen and Multigrade only
SA	Wearing course	Nil	
	Intermediate & base course	15%	20% if C170 used
VIC	Wearing course	10% for highway 20% for streets	If PMB not used If C170 used
	Intermediate Base course	20% 30% 40%	If C600 not used No additional testing Additional testing
NSW	Wearing course	15%	20% after 3 years performance
	Intermediate & base course	15%	25, 30 & 40% after 2, 3 &5 years performance

The main reason for the low percentage of RAP being allowed in specifications is based on the misperception that RAP will adversely impact on the performance of the new asphalt. These perceptions relate mainly to, but are not limited to, the effect the variability of the RAP and particularly the aged binder will have on the long term performance of the asphalt. In other words the incorporation of RAP could cause premature cracking or ravelling of wearing courses due to excessive hardening of the binder. Other concerns include the idea that RAP could reduce the skid resistance of wearing courses or negate the benefits of polymer modified binders to mention a few.

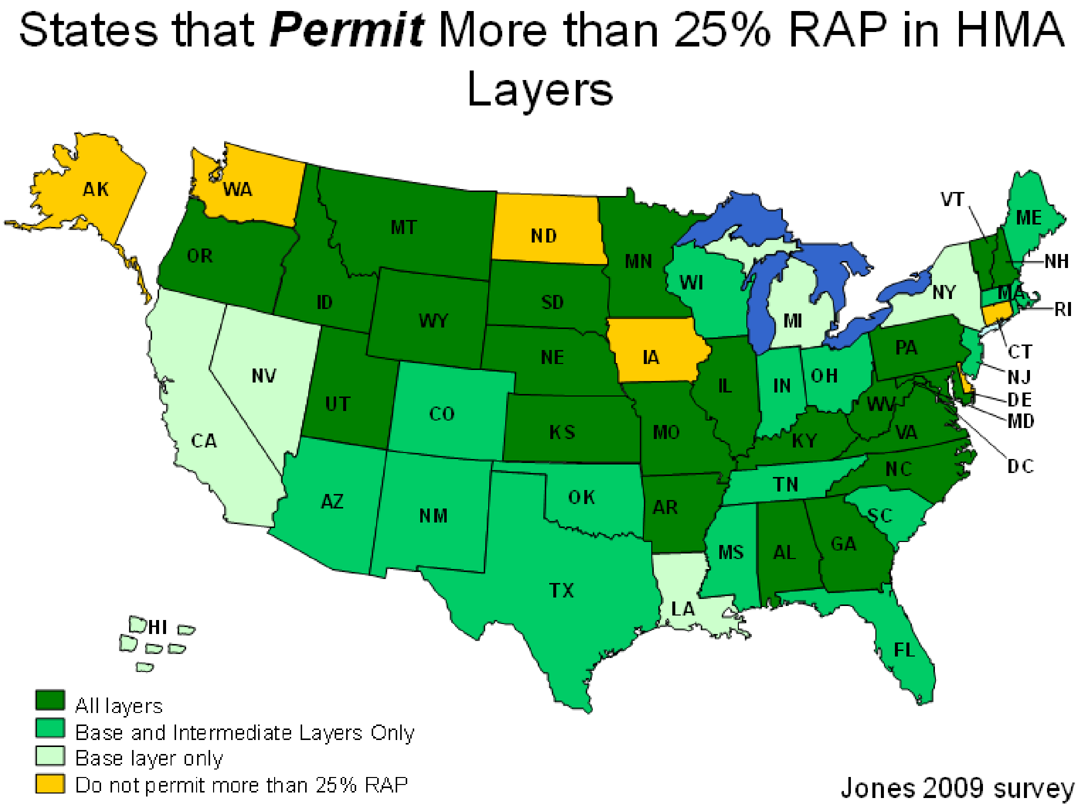
Notwithstanding the latter concerns, the manufacturer also has to overcome some major challenges which include inter alia plant capability, mix type and application, RAP availability and quality in order to increase the use of RAP above 15% to ensure adequate asphalt performance in the longer term. This paper will describe the journey under taken by Boral Asphalt to manufacture asphalt with up to 30% RAP at their asphalt plant in Sydney without compromising the performance of the final product.

2. Global best practice on the use of RAP

RAP is an appreciating asset and considered as a hedge against rising bitumen and oil prices especially in times of global uncertainty. To extract the best value from RAP its use is best optimised through replacing the more expensive bitumen and aggregates in the upper layers of the pavement.

The recycling of RAP in asphalt is fairly widespread practice in developed countries with 80% being used in the USA, while more than 98% is recycled in Japan. In the Netherlands, Germany, Denmark and Luxemburg more that 50% of new asphalt contains some recycled asphalt material and up to 50% RAP is added to mixes. Approximately one hundred million tonnes of RAP is generated annually in the USA and this equates to 17% of all new asphalt consisting of RAP. A study conducted by the National Asphalt Pavement Association revealed that 23 state DoT's had experience with recycling up to 25% RAP in asphalt. Figure 1 below shows the use of RAP in various pavement layers across all the DoT's in the USA.

Figure 1: NAPA survey on the use of RAP in USA



Studies conducted by NCAT into the performance of RAP showed that:

- Increasing the % of RAP reduces the potential of a mix to rut.
- Adding high % of RAP to a mix is reported to stiffen the binder to a higher performance grade. It was reported that substituting 50% RAP for 4% PMB was found to render the same rutting performance in wearing courses.
- Increasing the % RAP up to 40% does not increase the coefficient of variability of the asphalt mix provided the RAP is correctly managed and tested.

Long term pavement performance monitoring was carried out on 18 test sections across the USA on virgin and recycled asphalt mixes which had been in-service for up to 17 years. The findings were as follows:

- Pavements using ≥ 30% RAP are performing well, and in most cases, rutting performance was equal to virgin pavements
- Transverse and fatigue cracking were observed more often in some pavements with RAP compared to pavements with all virgin materials
- Differences in cracking performance for several locations may have been due to higher dust contents and/or lower asphalt contents

The results of the LTPP monitoring are shown in Table 2 below.

Distress Parameter	Virgin Performed Better than RAP	RAP Performed Better than Virgin	Insignificant Difference Between RAP and Virgin	RAP Performed Equal or Better Than Virgin
IRI	42	39	19	58
Rutting	33	29	38	67
Fatigue Cracking	29	10	61	71
Longitudinal Cracking	15	10	75	85
Transverse Cracking	32	15	53	68
Block Cracking	3	1	96	97
Raveling	7	15	78	93

The latest thinking in the USA is to base the criteria for deciding on the maximum percentage of RAP to use in a mix on the net effect that the aged binder in the RAP has on the properties of the new recycled mix. In other words the limiting factor for determining the maximum RAP % will be based primarily on the properties of the recovered aged binder and the binder content of the RAP. For example, a coarse graded RAP will typically have a lower binder content compared to a fine RAP e.g. 4 vs 7%. This means that almost double the amount of coarse RAP could be used in a mix vis-à-vis a fine RAP for the same amount of aged binder.

3. Program to assess performance of RAP in asphalt

The RTA in NSW amended their R116 specification for heavy duty dense graded asphalt to allow for increased amount of RAP to be use by introducing an approval process based on a system of performance verification, including materials testing and the implementation of process controls. This included the development of a RAP Management Plan (RMP) which must form part of the project quality plan in order to address the requirements of the specification. The RTA place the onus on the asphalt supplier to provide a history of performance should they wish to use more than 15% RAP in any asphalt dense graded mix with the following requirements:

Table 3: RTA's permissible RAP limits for dense graded asphalt

RAP level	Intermediate and base courses		Wearing courses	
	Max RAP (%)	Performance period (years)	Max RAP (%)	Performance period (years)
1	15	Nil	15	Nil
2	25	2	20	3
3	30	3		
4	40	5		

For RAP approval level 3 and 4 to be achieved:

(i) The processed RAP material must be screened into at least two fractions (coarse and fine) and each fraction must be separately metered into the asphalt mixing process.

(ii) The RMP must state how to ensure that the processed RAP material within a stockpile is at a moisture content which will not affect the asphalt properties.

(iii) Performance testing must be conducted to establish an optimised mix design.

(iv) Warm mix asphalt may contain RAP material, provided it does not exceed RAP approval level 1.

Given that the RTA had provided a frame work in which to increase the amount of RAP, Boral embarked on an extensive program to undertake plant trials to evaluate the operational and performance aspects of incorporating high percentages of RAP in to asphalt at their Astec double drum asphalt plant located at Enfield. The objective of the trials was to develop data to improve our understanding of the influence that increased percentages of RAP would have on the performance properties of the asphalt. This was done by:

1. Monitoring the consistency of the processed RAP
2. Conducting laboratory tests to measure the effect of the RAP on the volumetric and engineering properties of plant produced mix
3. Monitoring the in-service performance properties of the asphalt after two years

A detailed test program was developed in conjunction with the RTA to manufacture and lay trial mixes of AC14 heavy duty asphalt base and wearing courses manufactured using AR450 bitumen and various percentages of RAP. Mixes containing nil, 15, 20, 25 and 30% RAP were placed on Henry Lawson Drive in Bankstown. The following tests and evaluation was carried out on the mixes:

Table 4: RAP test plan

RAP	Plant samples	In-situ cores
Binder content	Volumetrics	Air voids
Recovered binder viscosity	Resilient modulus	Moisture sensitivity
Moisture content	Wheel tracking	Visual assessments
Particle size	Fatigue	
	Recovered binder viscosity	

4. Processing and management of RAP

Suitable road profiling material is transported direct from the road site to the Enfield plant for processing. Surplus RAP is stored at a remote area way from the plant for processing at a later stage. The RAP is passed over a vibratory multi-deck screening plant where it is graded into 3 fractions, namely minus 19, 14 or 7 mm maximum particle sizes. Any over sized RAP is processed through a granulator where it is broken down into smaller particle sizes for rescreening. Once the RAP has been screened it is stored in a covered bunker to prevent any ingress of moisture from rain. The dry RAP fractions are sampled daily prior to being feed into the RAP cold feed bins.

Key to the successful use of RAP was the development of specific procedures for the procurement, handling and processing of the RAP to ensure a consistent end product for use in asphalt. To this end a comprehensive review and upgrade of the RAP management practices were undertaken to ensure that a controlled and consistent quality RAP is used in the manufacturing process and was compliant with RTA Technical Direction TD 2005/06:OSD06. The ongoing monitoring of the key variables of the processed RAP is very critical to ensure uniform quality of the asphalt. The amount and properties of the aged binder in the RAP was measured along with the moisture content and the gradation of the various RAP fractions. This included daily testing and statistical monitoring of the key RAP variables, being; binder content, moisture content, % passing 0.075 and 2.36 mm sieves. Statistical Process Control charts were developed and the staff were trained to track the values against acceptable tolerance limits to ensure adequate management of RAP consistency. When out of tolerance results were obtained the cause was investigated and action taken to rectify to ensure continuous improvement.

Figure 2: Typical SPC charts showing RAP binder content variability

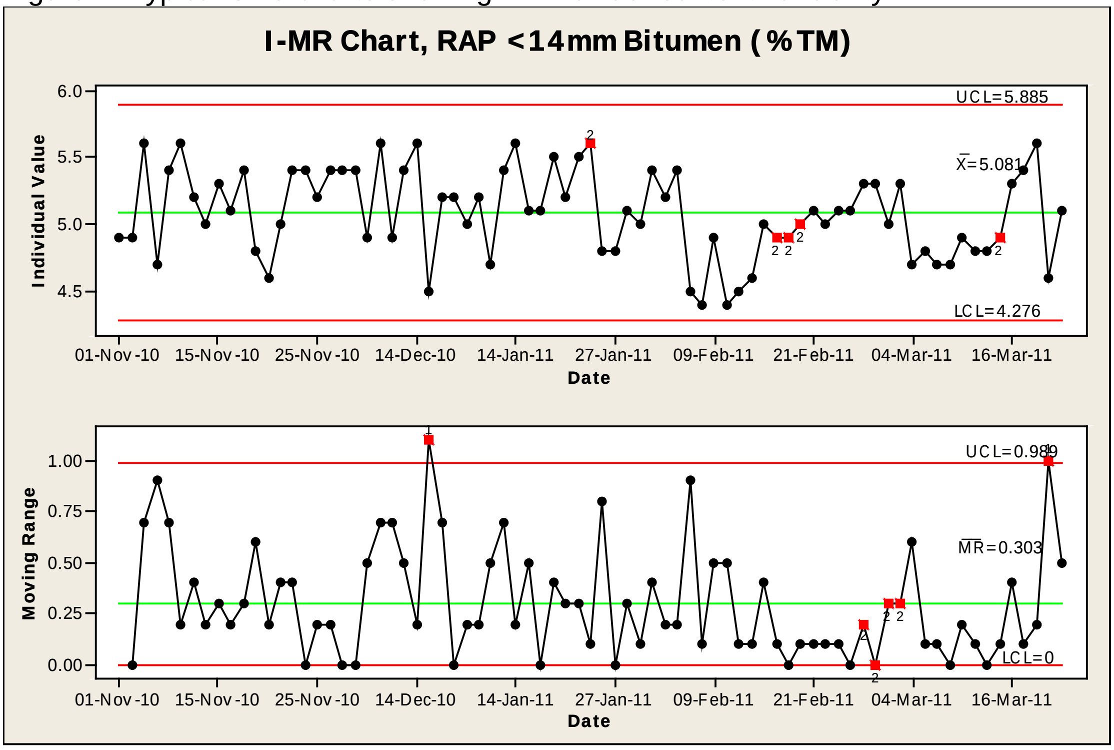


Figure 3: Typical SPC charts showing variability in RAP moisture %

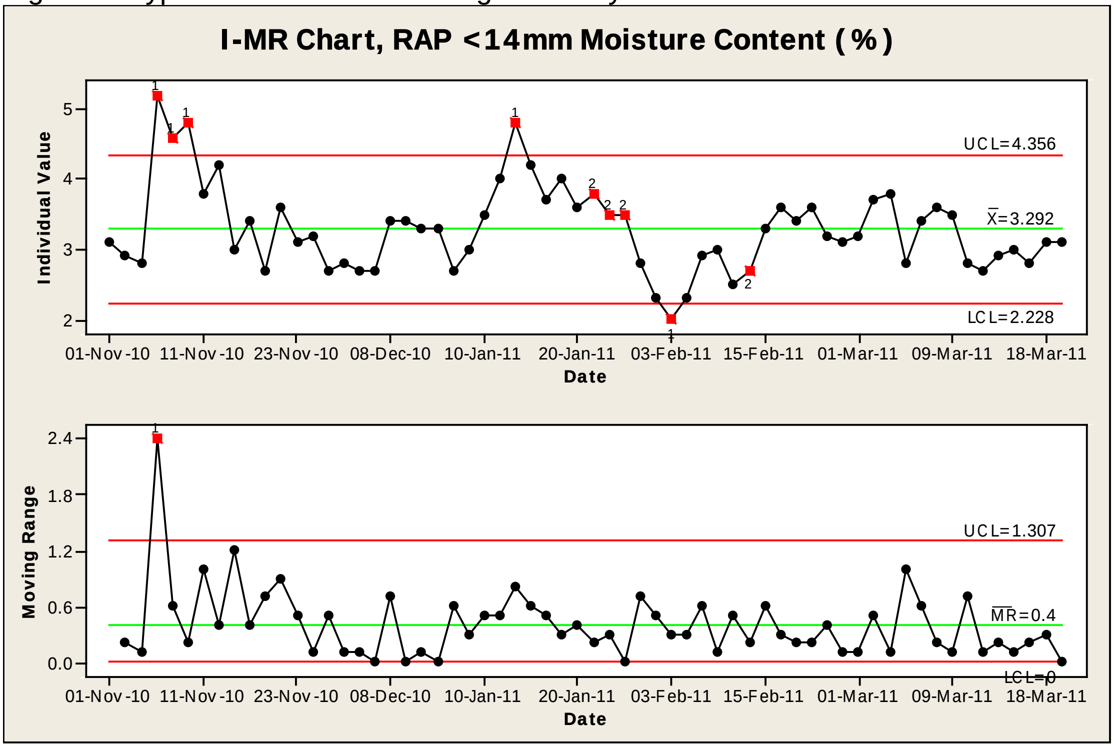


Figure 4: Typical SPC charts showing % RAP passing 0.075 mm sieve

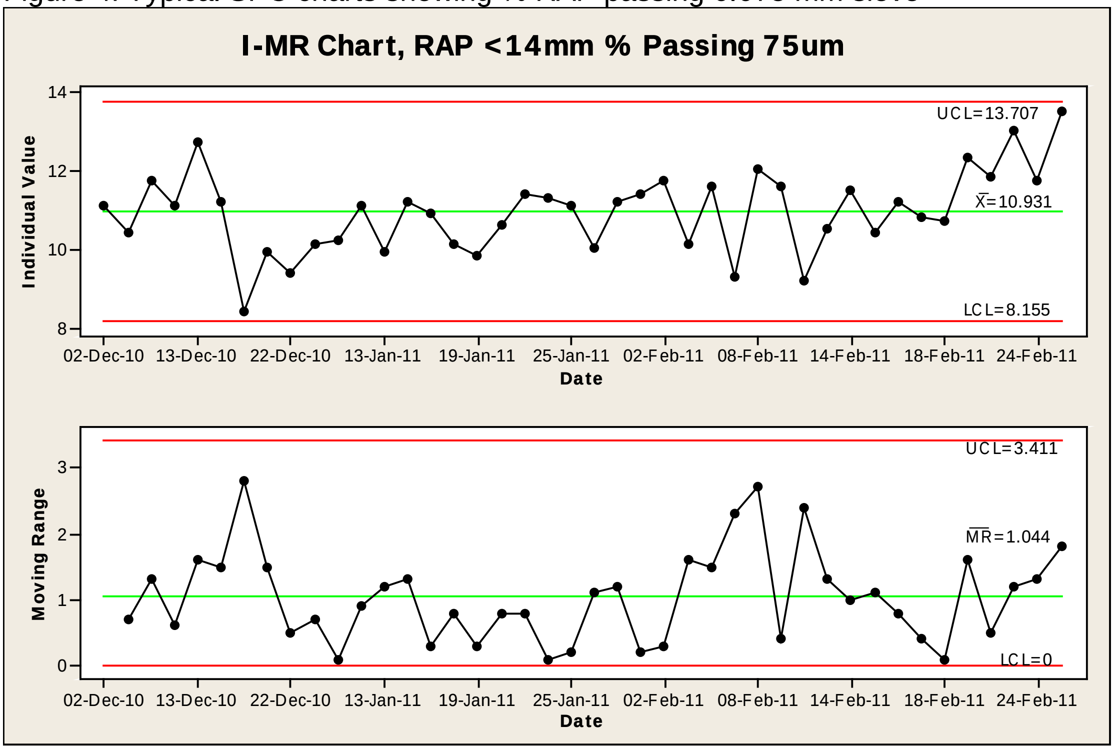


Figure 5: Typical SPC charts showing % RAP passing 2.35 mm sieve

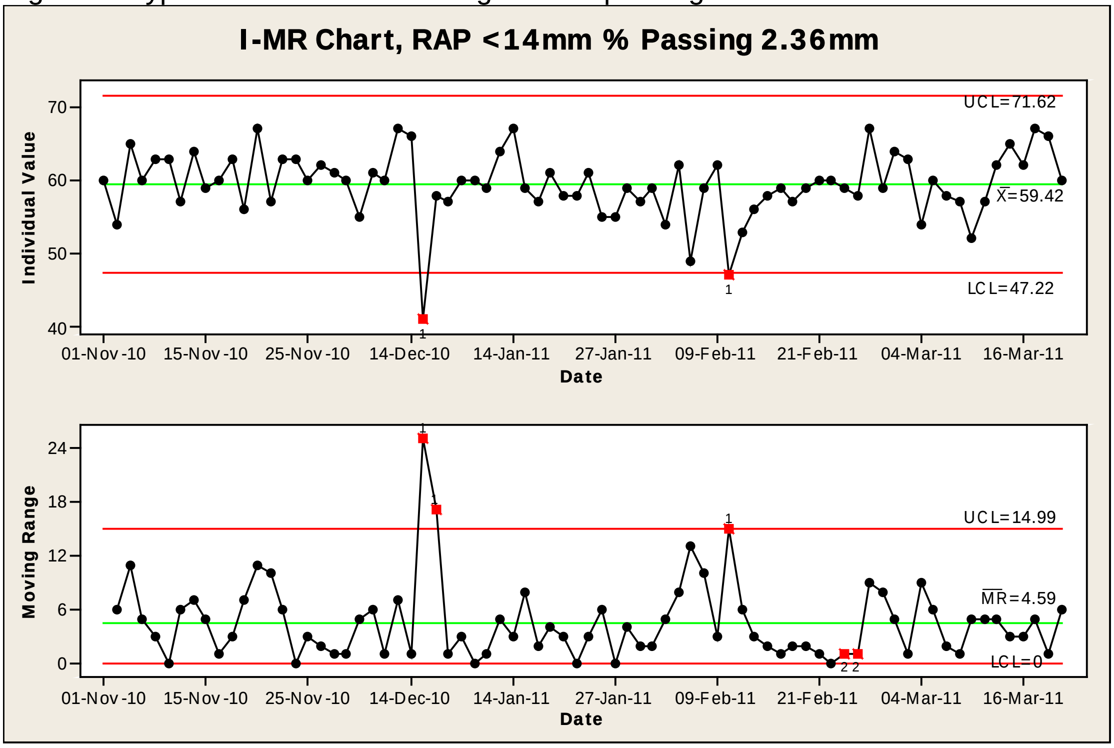
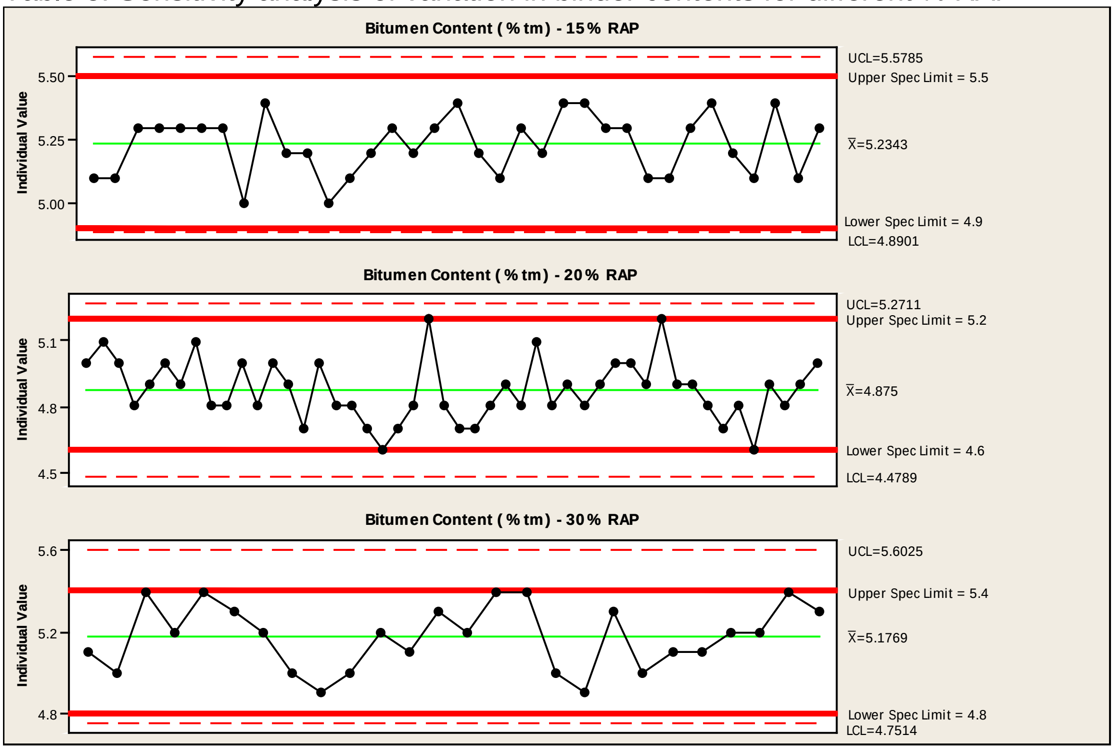


Table 5: Sensitivity analysis of variation in binder contents for different % RAP



These graphs show that even when the RAP percentage is increased to 30% there is no significant increase in variation of the resultant binder content of the new mix. In other words if the binder contents of the RAP is monitored and action is taken when the value exceeds the limits then the final binder content should remain within ±0.3% of the target value.

5. Performance test results and discussion

5.1 Laboratory mix design

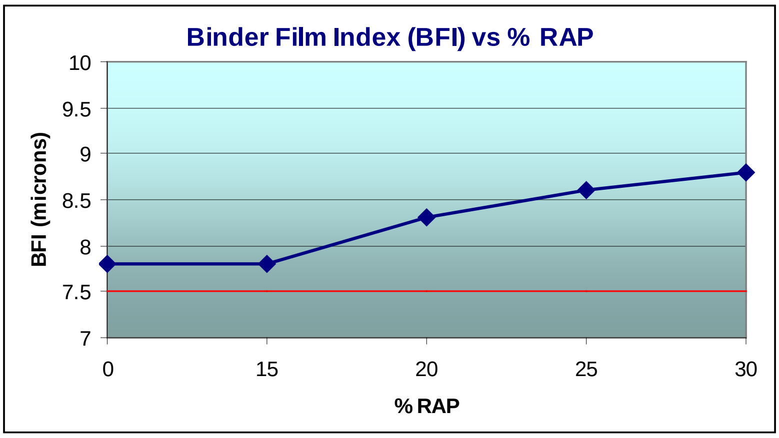
Preliminary laboratory work was undertaken at the various % RAP to ensure that the mixes complied with the design requirements for AC14 heavy duty dense grade asphalt as shown in table 5.

Table 6: AC14 heavy duty dense graded asphalt mix requirements

Gradation	Target	Property	Target
% Passing by Wt	19.0mm 100 9.5mm 73-87 6.7mm 58-72 4.75mm 45-59 2.36mm 31-41 1.18mm 20-30 0.600mm 14-22 0.075mm 3.5-6.5	Air voids after 120 gyratory compaction: Binder content: VMA: Binder Film Index:	3 – 6% 5.2 ± 0.3% Min 15% Min 7.5um

Because the RAP is a well graded product it is relatively easy to incorporate into the design of the overall asphalt gradation through adjustments to the proportioning of coarse and fine aggregate components. More critical to the design process is the allowance for the filler component and binder contributed by the RAP. It is important to maintain the correct volumetric properties and the binder quantity to ensure good air voids and binder film thickness. As can be seen in the following graph, by controlling the filler component and correct binder contribution, the binder film increased with the increasing level of RAP and the air voids were well controlled.

Figure 6: Maintaining Binder Film Thickness in Mix Design



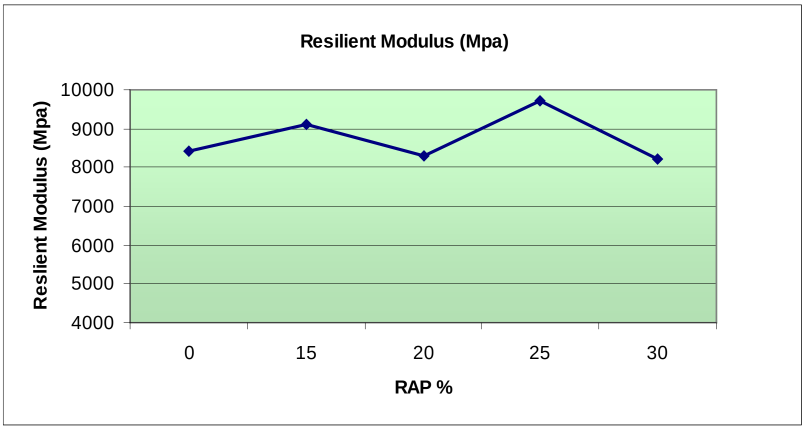
5.2 Laboratory performance tests on plant produced mix

Samples of production mix were taken of the various mix compositions and subjected to performance testing at the Boral Materials Testing Laboratory in Baulkham Hills. Extensive laboratory tests were undertaken to measure changes in the binder viscosity and rut resistance, resilient modulus and fatigue of the plant produced mixes with increasing percentages of RAP.

5.2.1 Mix performance tests

Table 7: Summary of mix performance test results

PERFORMANCE VALUES					
RAP %	**0**	**15**	**20**	**25**	**30**
Resilient Modulus (Mpa)	8400	9100	8300	9700	8200
Fatigue Life (cycles to Failure @ 400$\mu\varepsilon$	24000	73000	61000	37000	103000
Wheel Tracking - tracking depth (mm)	3.0	3.5	4.2	4.4	2.8



The resilient modulus results indicate a relative stiff mix however there is no trend of increasing stiffness with higher levels of RAP.

Figure 7: Repeated flexural bending beam fatigue test

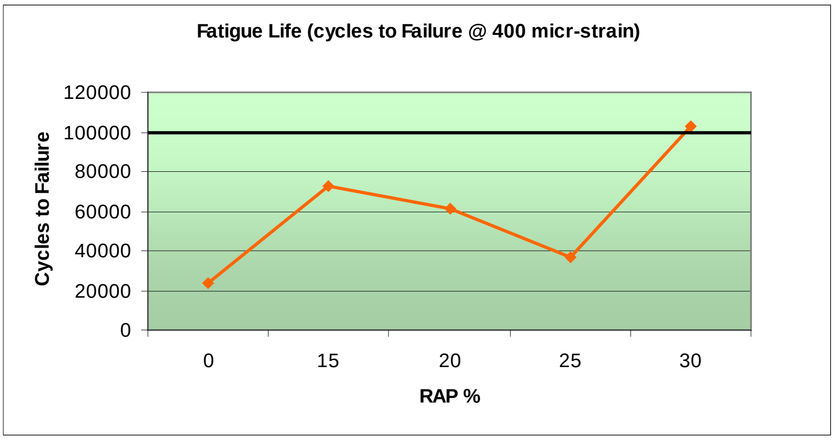
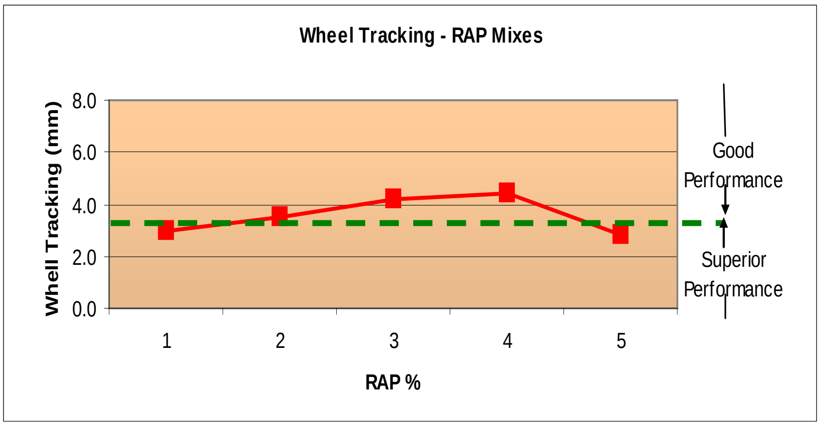


Figure 8: Wheel tracking test results



The wheel tracking results show no significant increase in rutting potential. All the results can be classified as good to superior performance category.

The mixes with RAP showed an increase in the fatigue vis-à-vis the control. This trend was not always incremental with increasing percentages of RAP with the 30% RAP mix achieving a substantially higher value.

5.2.2 Recovered binder viscosity

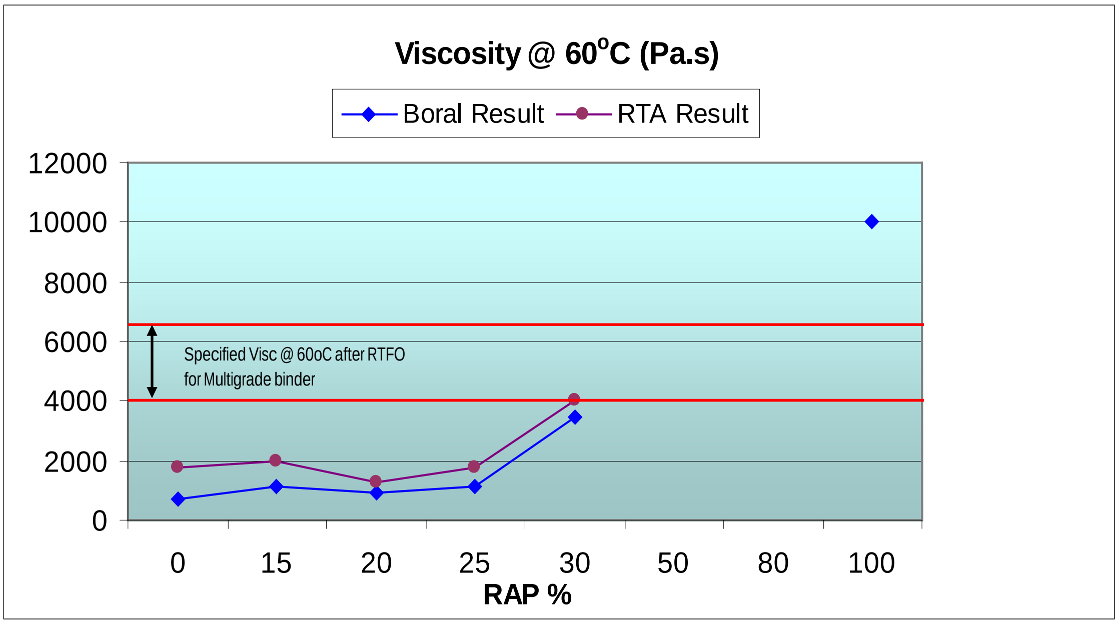
The binder was recovered from the recycled asphalt mixes and the viscosities were measured at 60 °C to monitor the change in viscosity at different RAP percentages. These values were also compared with the virgin and RTFOT results of the base AR450 bitumen used in the mixes. The results obtained by Boral are the average of 5 tests performed on each mix sample.

Table 8: Summary of recovered binder viscosities @ 60 °C (Pa.s)

% RAP	0	15	20	25	30
Batch Viscocity @ 60°C (Pa.s)	488	488	480	483	502
Batch Viscocity @ 60oC after RTFO (Pa.s)	794	794	866	827	850
Recovered Bitumen Properties					
Viscocity @ 60°C (Pa.s) Calculated** (Boral)	682	1106	943	1135	3472
Viscocity @ 60oC (Pa.s) Calculated** (RTA)	1724	1979	1280	1732	4044
Recovered Penetration (RTA) (m x 10^{-4})	19.5	19.5	23	20	15

The recovered binder viscosities do not show a marked increase from the control for mixes containing RAP up to 25%. The recovered binder viscosities obtained by Boral for the mixes with up to 25% RAP were in line with what would be tolerated for a recovered C450 bitumen without RAP. There was a step difference in the values obtained by Boral and the RTA for the same mixes although the trends were the same. This can be attributed to the poor reproducibility limit of up to 45% for the test method. At 30% the recovered binder viscosity showed a marked increase which is similar to the value one would expect for a 320/1000 Multigrade bitumen. The penetration values on the recovered binder for all the mixes where below the minimum penetration requirement limit of 26 dmm for multigrade binder after RTFOT.

Figure 9: Comparison of recovered binder viscosities @ 60 °C (Pa.s)



More testing is required to substantiate and militate against the large change in recovered binder viscosity at RAP levels above 25%. Consideration should be given to changing to either a softer grade of bitumen or utilise warm mix technology to overcome the marked increase in binder viscosity with the incorporation of more than 25% RAP in the mix.

5.3 In-situ performance tests

The mix was placed as a base and wearing course on Henry Lawson Drive and in-situ cores were taken from the pavement immediately after placement and two years later for further testing. The cores were subjected to the RTA's T649 test to measure moisture sensitivity of the mix from both the wearing and base courses. The cores were subjected to modulus and tensile strength testing in dry and wet conditions.

Figure 10: Tensile strength of base course

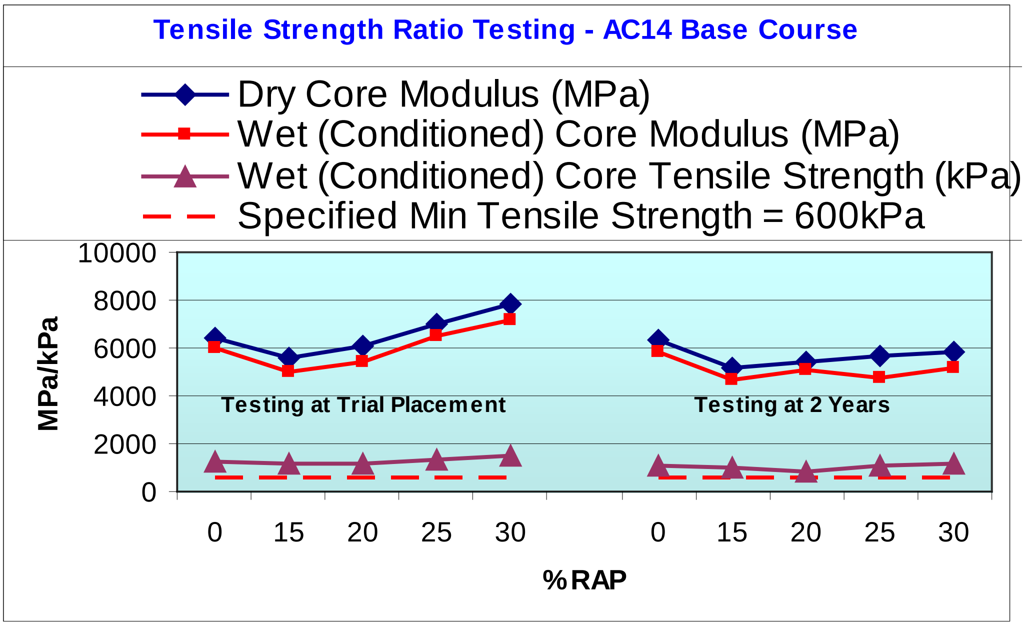


Figure 11: Tensile strength of wearing course

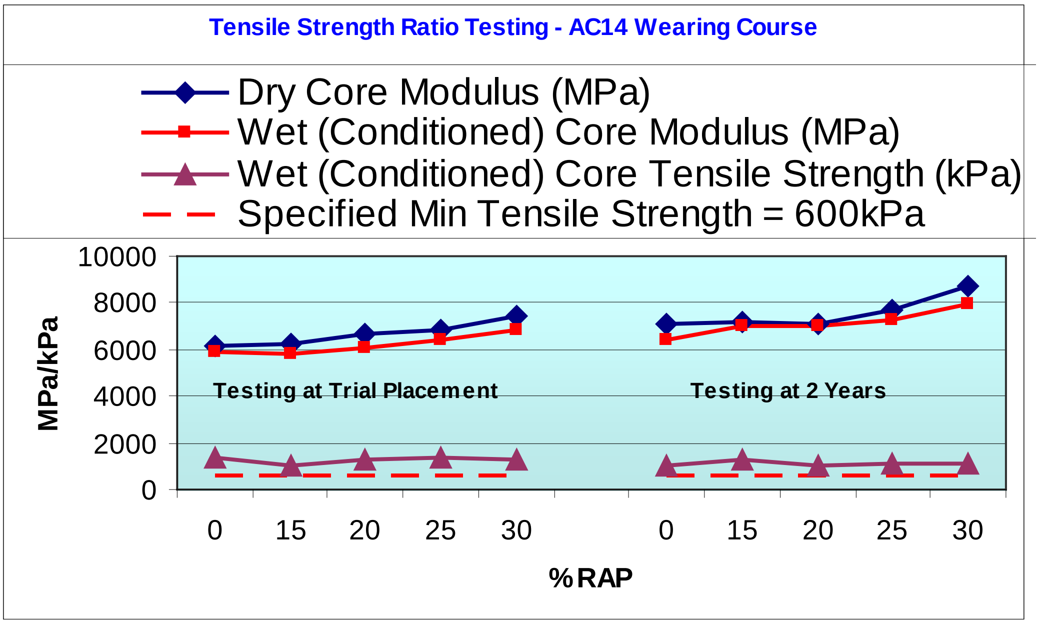
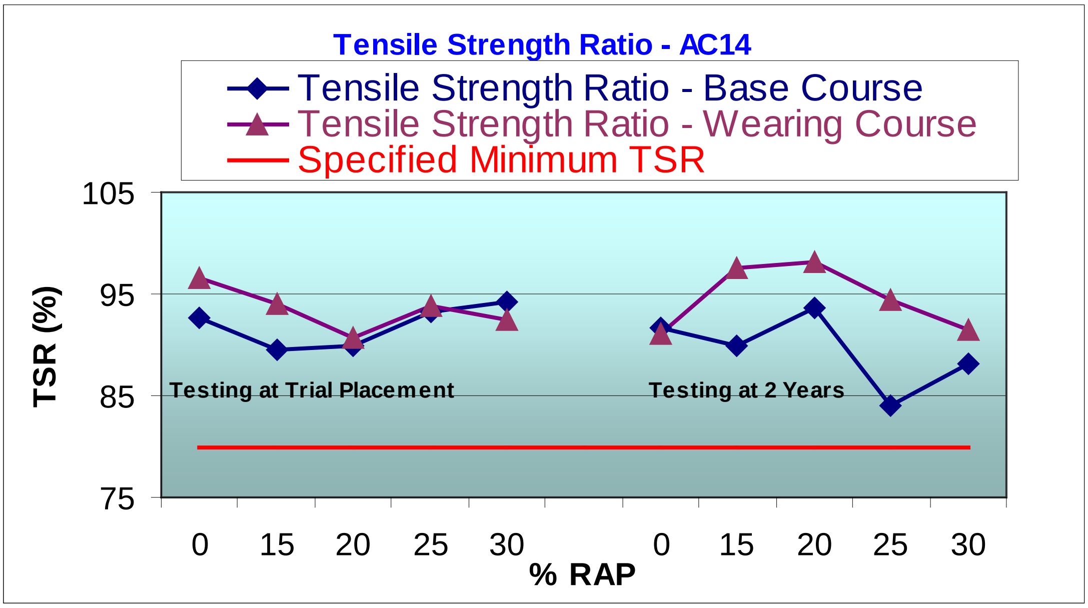


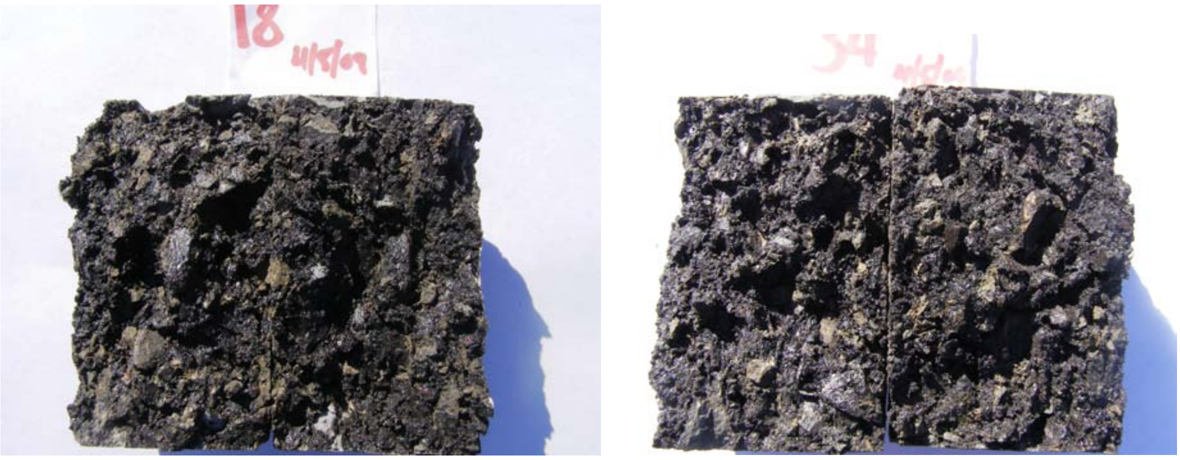
Figure 12: Tensile strength ratio of base and wearing courses



The results for both the retained modulus and retained modulus ratio (TSR) showed that

- All mixes passed the specification requirements with ease even after two year in-service life.
- The retained modulus increased slightly with the increase in RAP content except for the base course where the values remained similar to the control after two years.

The visual assessment of the cores from the pavement did not show excessive stripping. The results generally fell into the minimal to moderate ranking for coarse aggregate and a nil ranking for the fine aggregate.



Photographs of cores containing 25% and 30% RAP after TSR conditioning and splitting

6. Economic benefits of recycling

There are numerous economic benefits to the asphalt supplier, client and the communities to recycle RAP in asphalt.

The cost of processing RAP must be cheaper for the asphalt manufacturer than the cost of the raw materials it replaces ie bitumen and aggregates to be economically viable. These cost savings should also include the savings in transport and heating of bitumen whereas a further cost savings should be realised in a proportional reduction in the heating of less virgin aggregate if the RAP moisture content is kept to a minimum. These cost savings in turn will be passed onto the client in a competitive market environment and act as a hedge against rising bitumen and aggregate prices. If one considers the cost of the original asphalt, the RAP value has appreciated over time given that its new value reflects the materials it replaces less the processing cost of the RAP.

With increasing pressure being placed on preserving our non-renewable resources and reducing our carbon foot print there are added economic benefits of increasing the utilisation of RAP in the manufacture of asphalt. The quarries are slowly exhausting the availability of quality aggregates for asphalt and the recycling of RAP helps preserve our limited sources. In the case of wearing courses where there is concern over the polish stone value of the plus 14 mm aggregates, use should only be made of minus 14 mm sized RAP in the mix.

A comparison was done between using all virgin materials and various RAP contents to compare the savings in the energy and green house gas emissions which would achieved in the Enfield plant.

	Zero RAP	**Current RAP Level for RTA asphalt mixes**		**+ additional 10% RAP in RTA asphalt mixes**	
	Usage	**Used**	**Benefit vs Zero RAP**	**Used**	**Benefit vs Zero RAP**
Virgin Agg & Sand[1]	116,389 T	96,409 T	(19,980 T)	84,770 T	(31,619 T)
Virgin Binder[1]	6,774 T	5,611 T	(1,163 T)	4,934 T	(1,840 T)
RAP Used[1]	0	21,143 T		33,459 T	
Energy Used[1]2	72.8 GJ 591 MJ/T mix	55.6 GJ 451 MJ/T mix	(17.2 GJ) (140 MJ/T mix)	46.4 GJ 377 MJ/T mix	(26.4 GJ) (214 MJ/T mix)
CO2-eEmission1,2 **(GHG's)**	5,788 T 47 kg/T mix	4,472 T 36 kg/T mix 77% of zero RAP level	(1,316 T) (11 kg/T mix)	3,750 T 30 kg/T mix 65% of zero RAP level	(2,039 T) (17 kg/T mix)
Federal Target GHG		Maintain ave of 108% of 1990 levels for 2008-12		Target 85-95% of 2000 level by 2020	

7. Summary and conclusions

These trials showed that by properly managing and monitoring the consistency of the incoming RAP a quality high performance asphalt mix can be produced using high percentages of RAP.

The results reported in this paper are in line with USA experience which shows that the performance of the asphalt is not compromised in terms of rutting, fatigue, stiffness and moisture sensitivity with the incorporation of up to 30% RAP in wearing and base courses. In all cases the mixes with RAP rendered superior performance characteristics and in most cases obtained equivalent or better results than those without any RAP. These findings should go a long way in dispelling the misconceptions that mixes with RAP are inferior to mixes with only virgin materials.

The improvement in asphalt performance properties were achieved without changing the grade of bitumen. The RTA should give consideration to increasing the RAP in wearing to up to 25% without changing the bitumen grade for heavy duty asphalt mixes. Further testing needs to be done to investigate using either C170 bitumen or warm mix technology to increase the RAP content above 25% for heavy duty wearing courses to offset the increase in binder viscosity.

The use of RAP offers the industry a valuable opportunity to meet the sustainability targets and increase utilisation will allow significant further reductions in energy and green house gas emissions through the reduction in demand for virgin bitumen and aggregates.

7. Acknowledgements

The authors of this paper would like to acknowledge the efforts of the staff at Enfield in accommodation these changes to improving the processing of RAP and the support of the RTA in carrying out these trails.

8. References

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