ONTARIO ASPHALT PAVEMENT COUNCIL

THE ABCs OF RAP

More than steel, more than plastic, more than paper - asphalt is North America's number one recycled material.

In 2015, in the US alone, contractors reused and recycled 70 million tonnes of asphalt[1]. That is an impressive amount. In the same year, 77 million tonnes of reclaimed asphalt pavement (RAP) was stockpiled across the US for future use[2].

THE ABCs OF RAP

The volume of recycled asphalt pavement is…

- 13 TIMES greater than recycled newsprint.
- 27 TIMES greater than recycled glass bottles.
- 89 TIMES greater than recycled aluminum cans.
- 267 TIMES greater than recycled plastic containers.

Reclaimed Asphalt Pavement:

- Saves dwindling aggregate resources.
- Recovers non-renewable petrochemical resources.
- Diverts large volumes of materials from overloaded landfills.
- Reduces road building costs.
- Contributes significantly to provincial and municipal recycling obligations.

Reclaimed asphalt pavement is used to build:

- New roads
- Roadbeds
- Shoulders
- Embankments

For roadbeds, shoulders and embankments, where engineering properties are of less concern, RAP is perfectly acceptable as "black rock", as a supplement blended with virgin aggregate. However, black rock simply takes advantage of the aggregate in RAP. It is only when RAP is used as a hot mix raw material that engineers can take full advantage of the engineering properties of both the aggregate and asphalt cement and can then maximize the economic value of recycling.

Since the late 1970s when it was first used as an engineered material, millions of tonnes of RAP have been used in hot mix. And the results are unequivocal. Using RAP reduces costs without any impact on performance.

But (and it is a big BUT), asphalt pavement is not a linear landfill. Yes, using recycled asphalt is good for the environment. Yes, recycled asphalt can save costs. But don't lose sight of the primary objective - producing long-lasting, durable, high performance roads, which requires the right materials, design and methods and knowing the ABCs of RAP.

RAP – FROM ONE ROAD TO THE NEXT

Reclaimed Asphalt Pavement, as the name implies, comes from old roadways that have passed their useful life.

Just because the road has exceeded its useful life doesn't mean that the asphalt material has too. Step-by-step, this is how one road is transformed into another.

An asphalt pavement has two key components: the aggregate and the asphalt cement. The aggregate, which makes up about 95% of the asphalt concrete, provides the pavement with its strength and load carrying capacity. The asphalt cement, which binds the aggregate together, adds strength and flexibility to the pavement.

Using RAP for hot mix saves on both the the aggregate and the asphalt cement, both of which come from non-renewable resources.

RAP Supply, Storage and Processing:

Before repaving a road, a contractor either mills the top layer of the old asphalt pavement or removes the old asphalt pavement entirely and then takes the RAP to a central yard for processing and stockpiling.

The key to success is proper management and processing. In order to ensure that the performance characteristics of RAP are equivalent to those of virgin material, the RAP is blended, screened and crushed to produce consistent aggregate gradation and asphalt content. During processing and stockpiling, Quality Control testing is completed for both material quality and material variability. The homogeneous blends of RAP are then inventoried and stockpiled.

RAP should be stored in an open sided shed or building to keep the stockpile dry and minimize the moisture content. It should not be covered since tarps can trap moisture.

RAP as a Raw Material:

The properties of RAP depend not just on the properties of the pavement from which it was recovered but also on how it was recovered, processed, and stockpiled.

- The aggregate gradation of RAP recovered by milling will be finer than the RAP from excavated chunks of pavement due to the mechanical degradation from milling.
- Crushing RAP to a single size generally results in additional fines (material passing the 200 µm sieve size) being generated.
- Processing RAP from different sources into one stockpile can produce a consistent processed RAP if good loading and mixing practices, in combination with quality control testing are used.
- RAP identified as containing contaminants is removed during processing and is best suited for use in other non-asphalt mix applications.
- The size of processed RAP stockpiles are established based on rate of anticipated use at the asphalt plant with consideration for the available space. Good stockpile management and sizing practices are essential to prevent contamination of stockpile bases and segregation of excessively large stockpiles.

Screening, or fractionating, processed RAP into different size fractions allows control of the maximum aggregate size added to different mix types and allows more control of mix properties. When RAP is produced with the intention of splitting into different fractions, the recycled pavement material is screened with crushing of the recycled pavement limited to breaking up the existing chunks to a predetermined top size of typically less than 50mm.

Limiting the amount of crushing results in less breakage to the aggregates in the RAP and reduces the amount of fine material generated (passing 200 µm sieve). The screened and crushed material is then split into size fractions, appropriate for use in different mix types with each size fraction stockpiled separately. ***It is important to consider that the asphalt cement content of the processed fractions will be different than the parent recycled material and asphalt cement content of each size fractions will also be different.***

Typically, finer fractions of processed RAP will have at least 1% more asphalt cement than coarser fractions. Understanding the exact amount of AC in each fraction is critical and must be determined through quality control testing.

It is absolutely essential that the RAP in each stockpile is tested and the characteristics of the RAP clearly defined so that an appropriate mix design can be developed. Typically, RAP should be tested for:

PROPERTY	FREQUENCY	MINIMUM NUMBER OF TESTS PER STOCKPILE	MAXIMUM STANDARD DEVIATION
Asphalt Content	1 per 1,000 tonnes	10	0.5
Recovered Aggregate Gradation	1 per 1,000 tonnes	10	5.0 all sieves 1.5 on 75 micron
Recovered Aggregate Bulk Specific Gravity	1 per 3,000 tonnes	3	
Binder Recovery and PG Grading (For Blends Greater than 30% RAP)	1 per 5,000 tonnes	1	

In addition to the routine RAP quality tests above, aggregate physical properties, consensus properties and a petrographic review should be completed to ensure compliance to requirements and standards related to the specific mix types to be produced with the processed RAP.

RAP Content:

The current method of specifying allowable RAP content in hot mix in the Ontario Provincial Standard Specifications and Municipal Specifications is based on a percentage of RAP by mass of total aggregate. The percentage specified assumes the RAP being used has been removed from a typical pavement and that the processed RAP has not been modified from its original composition with the exception of screening or crushing.

The current Ontario Provincial Standard Specifications, OPSS 1150 issued December 2006 provides the following limits for RAP use.

- Up to 15% RAP in conventional surface mixtures.
- Up to 20% RAP in Medium Duty Binder Course mixtures.
- Up to 30% RAP in conventional base/asphalt cement mixtures.
- Up to 50% RAP can be used in certain situations provided that testing demonstrates that the quality of the PGAC has been maintained.

Municipal specifications may vary from the OPSS 1150 requirements and could specify different allowable percentages of RAP in the mixes specified for use in their jurisdiction.

When fractionated RAP is used in hot mix that is specified to contain a maximum percentage of RAP, the amount of fractionated RAP used in a mix must be adjusted and balanced to account for the percentage of Asphalt Cement in the fractionated RAP versus the AC content of a non-fractionated RAP. There is potential for negative impact to low temperature performance of the combined asphalt cement in the mix if the AC content of the fractionated RAP is not considered with percentage RAP specifications.

Binder Replacement Ratio

An alternate method of defining the amount of Recycled Asphalt Pavement in a mixture is the RAP Binder Ratio. This method defines the total allowable amount of asphalt material from recycled asphalt present in a mixture based on the total percentage of asphalt in the mixture. The advantage of the Binder Ratio versus Percent RAP is that the percentage of aged AC in the mix can be controlled as the AC content of all recycled products in the mix are accounted for. This method removes the guess work required when recycled products with AC contents that differ than what is present in normal recycled pavements such as fractionated RAP.

The Binder Ratio is calculated:

$$\text{BINDER REPLACEMENT, \%} = \frac{(A \times B)}{C} \times 100\%$$

Where:

A = RAP percent binder content.
B = RAP percent in mixture
C = Total percent binder content in mixture

The binder replacement ratio can be used to approximate the allowable amount of fractionated RAP in a mix specified to meet a percentage RAP specification by substituting the allowable binder replacement percentage with the allowable percentage of RAP specified for the mix in question in the formula.

Mix Design:

Proper mix design involves:

1. Determining the material properties of the RAP.
2. Selecting an appropriate blend of RAP and virgin aggregate to meet gradation.
3. Selecting the appropriate PGAC for the environment and traffic.
4. Designing a mix to comply with the applicable mix design requirements (e.g. Marshall or Superpave).

In Ontario, the Superpave Mix design procedures for mixtures containing RAP are based on the Ministry of Transportation of Ontario laboratory standard: "LS307 Design Procedure for Recycled Hot Mix Asphalt". The Ontario procedure has implemented many of the recommendations made by The National Cooperative Highway Research Program (NCHRP) in the US and issued NCHRP 9-12, which includes a final report, "RAP – From One Road to the Next," and NCHRP Report 452. It should be noted that not all recommendations made by NCHRP have been implemented in Ontario at this

time. Marshall Mix design procedures, for use where Marshall mixes are still specified, can be found in The Asphalt Institute's Manual Series 2.- Asphalt Mix Design Methods, 7th Edition. Chapter 7.

Asphalt Cement Blending

Tests show that when the RAP content is low, there is little impact to the properties of the virgin asphalt cement due to blending with the recovered asphalt cement. In other words, the asphalt cement from the RAP does not affect the properties of the virgin asphalt cement. Therefore, no adjustment is needed when the RAP content is less than 15%. However as the RAP content is increased, the virgin asphalt cement grade must be adjusted.

NCHRP Report 752; "Improved Mix Design, Evaluation and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content" defines high RAP mixes as having a RAP Binder Ratio of more than 25%. Evaluation of the PG grading of the aged asphalt cement in the RAP is a recommended as part of standard quality control regardless of the intended RAP Binder Ratio to be used. However, for high RAP mixes the understanding of the PG grade of the aged AC becomes critical to ensuring low temperature performance of the asphalt mix in service.

For blends above 15%, the following table can be used as a guide for adjusting the Performance Graded Asphalt Cement to achieve the low temperature definition required for the project location.

BINDER REPLACEMENT RATIO	PERFORMANCE GRADED ASPHALT CEMENT*		
	Zone 1	Zone 2	Zone 3
0 – 15%	PGAC 52-34	PGAC 58-34	PGAC 58-28
16% - 25%**	PGAC 52-40	PGAC 52-40	PGAC 52-34
26% - 50%	Confirm Grade by Blending Chart – All Zones		

*Zones represent specific geographic areas in Ontario as developed for the use of PGAC.
**When higher grades of PGAC are specified select one grade softer. i.e: Use PG 58-34 if PG 64-28 is specified.

Blending charts are recommended to be used at all RAP Ratio Percentages above 15% but are considered necessary for High RAP mixes. Given the PGAC grade of the asphalt cement in the RAP and the RAP Binder Ratio, or percentage of RAP, to be used in the final hot mix, engineers can use a blending chart to determine the grade of virgin asphalt cement needed to achieve a final PGAC value. It should be noted that the Marshall Mix Design MS-2, NCHRP Report 452 and NCHRP Report 752 for Superpave have guidelines for using blending charts.

It should be noted that recovery of Asphalt Cement from aged or newly mixed hot mix using the current recommended test procedures involves the use of hazardous material and specialty safety equipment. Industry correlations completed at this time show that between laboratory variability is high with this test. Further, the impact to the properties of recovered Asphalt Cement modified with polymers or other methods required to meet newly developed PG+ testing specifications recently introduced to the province of Ontario, such as MSCR, Extended BBR, and DENT, are not fully understood at this time.

Given these unknowns and test variability, it is suggested that all results are critically looked at with results being closely reviewed by the engineer and mix designer against previously reported or known data from all available sources. All data should be catalogued to provide a reference and understanding of the potential variability. When using the data, the engineer and designer should err on the side of caution to allow for the known testing variability of the test method and the unknown impact to the modifiers used in manufacturing the grades of cement present.

Aggregate Selection:

When doing a Superpave mix design, the aggregate in RAP and the subsequent blend of RAP and hot mix must be tested for the consensus properties of:

- Specific gravity
- Coarse Aggregate Angularity
- Fine Aggregate Angularity
- Flat and Elongated Particles
- Gradation

Plant Production

Typically batch plants can process hot mix with up to 30% RAP content while drum plants can process up to 50%. RAP can be processed with only minor modifications to equipment and techniques. It should be loaded slowly into a separate cold feed bin with steep sidewalls. Air cannons may be needed to loosen any bridge formations. Use either a RAP gator or lump breaker to break up large chunks or a vibrating screen to remove oversize pieces or a combination of both.

In Batch plants an air scavenger system is needed to collect moisture and dust during the mix cycle to control any release of steam. An increased frequency of the wet and dry mixing cycles is also recommended.

Quality Control and Quality Assurance:

As with any hot mix production, quality control and quality assurance ensures that the final product meets all the necessary specifications. Quality control of hot mix containing RAP uses the same tests as any other hot mix to ensure that volumetric properties are being met and field density is being achieved.

Lay-Down Techniques

A properly designed, well-produced hot mix containing RAP should be no different from any other hot mix. Conventional lay down equipment and procedures can be used.

RAPPING UP
THE ECONOMIC AND ENVIRONMENTAL BENEFITS OF RECYCLING

The Provincial Potential

Ontario hot mix plants produce about 14 million tonnes of hot mix a year. Given the typical design life of pavement, the roads built with those 14 million tonnes will need to be rehabilitated in twenty years – just in the same way that we are now rehabilitating roads built in the late 1990s and early 2000s.

Rehabilitating a road doesn't mean ripping up the entire pavement and starting again. In most cases, a good proportion of the asphalt pavement will stay in place as the base course. But even if we assume that, say, 60% of the pavement will not be removed, that still leaves 5.6 million tonnes of pavement to be recycled.

Getting rid of that much asphalt would be an enormous burden on our landfills. Assuming that asphalt rubble occupies about 30% more volume than compacted asphalt (which itself has a density of 2,400 kilograms per cubic metre), it would need a landfill with 3 million cubic metres capacity to contain 5.6 million tonnes of asphalt pavement. To picture just how big 3 million cubic metres is, imagine two Skydomes filled with asphalt. The cost of disposing of this quantity of asphalt is equally impressive – about $700 million at current tipping fees.

Of course most asphalt is recycled, but using RAP as a "black rock" substitute for aggregate does not take advantage of the value of the asphalt cement in the RAP. Using RAP in hot mix does.

The 5.6 million tonnes of pavement that will need to be recycled in twenty years' time contains approximately 280,000 tonnes of asphalt cement, worth at current prices approximately $154 million. If the current production of hot mix in Ontario contained 20% RAP, we could recover about $42 million worth of asphalt cement a year – and $42 million builds a lot of roads.

The Municipal Example

Reuse and recycling only succeeds when everyone participates. Even though the Ontario Ministry of Transportation has a good hot mix recycling policy, the reality is the vast majority of road building in Ontario takes place on relatively small municipal projects. But even in a small municipal repaving project, RAP can help reduce costs and improve environmental performance.

Take a typical municipal road rehabilitation project: a two-lane arterial road one-kilometres long that, while structurally sound, needs some rejuvenation. The project calls for the top 40 millimetres of asphalt to be removed and replaced with a new surface course.

The contractor has to remove approximately 375 cubic metres of asphalt paving – about 900 tonnes. If the asphalt could not be recycled, at current tipping fees of around $120 per tonne it would cost around $110,000 to send that material to landfill.

Using RAP also reduces the cost of hot mix production since the RAP displaces virgin material. Even though the RAP is a recycled material and, without any other outlet, would be considered a waste product, it is not free. It still has to be transported, stockpiled and processed. However, by using RAP as a hot mix raw material rather than simply as a "black rock" aggregate, ensures the recovery of the asphalt cement component, currently costing about $550 per tonne based on the 2016 average Asphalt Cement Price Index. Using a blend of 20% RAP in a municipal rehabilitation project of this size should reduce costs by about $5,000 per lane kilometre.

Sources:

1. *National Asphalt Pavement Association. (2015).* Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage. *Retrieved from http://www.asphaltpavement.org/*
2. *National Asphalt Pavement Association. (2015).* Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage. *Retrieved from http://www.asphaltpavement.org/*

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A Council of the Ontario Road Builders' Association