Using Reclaimed Asphalt Pavement in Pavement-Preservation Treatments

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FOREWORD

The Federal Highway Administration evaluated using reclaimed materials in the highway program by documenting case studies, best practices, applicable tests, costs, and specifications for reclaimed asphalt pavement in pavement-preservation treatments, such as chip sealing, slurry sealing, and microsurfacing. This report provides recommendations on design criteria, material specifications, construction techniques, costs, inspections, and performance data that pavement-maintenance practitioners will find useful when developing and deploying pavement-maintenance programs.

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Director, Office of Infrastructure
Research and Development

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16. Abstract
Using reclaimed asphalt pavement (RAP) has grown significantly since the oil embargo of the 1970s. The National Asphalt Pavement Association reported that over 71 million tons of RAP were used in 2014 (NAPA 2015). RAP was traditionally used in warm-mix asphalt (WMA) and hot-mix asphalt (HMA) construction, including conventional and thin HMA overlays, but there is growing interest in using RAP in non-HMA projects, such as chip sealing and microsurfacing. Limits on the use of RAP in non-HMA pavement-preservation treatments are not as well known since there is limited research on how RAP affects the performance of such treatments. The purpose of this study was to investigate the performance of RAP in non-HMA pavement-preservation treatments to determine if performance trends similar to those found in WMA and HMA construction projects are evident. This study also documented current practices for using RAP in non-HMA pavement-preservation treatments, including guidance on design criteria, material specifications, construction techniques, costs, inspections, and performance data. Multiple agencies have used RAP in chip seals for a variety of reasons, including cost savings and environmental sustainability goals. One agency specified exclusively using reclaimed asphalt pavement aggregate in slurry seals (RAP slurry) sealing and microsurfacing, allowing full replacement of virgin aggregate. The performance characteristics of pavement-preservation treatments using RAP or virgin aggregate are similar, as are chip seal application rates and construction techniques. RAP slurry seals are reported to benefit from pneumatic-tire roller passes that seat the RAP particles and seal the treatment surface texture. During this study, several agencies reported either experimenting with or adopting RAP materials in pavement-preservation projects, suggesting continued use of RAP in pavement-preservation projects will continue.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
Caltrans	California Department of Transportation
CQS-1h	cationic quickset emulsion
CRS-2P	cationic rapid-setting type 2 polymer modified
CTM	California Test Method
DOT	department of transportation
ESAL	equivalent single-axle load
FDR	full-depth reclamation
FWD	falling-weight deflectometer
HFE100P	high-float emulsion with polymer
HMA	hot-mix asphalt
ID/IQ	indefinite delivery/indefinite quantity
ISSA	International Slurry Seal Association
JOC	job-order contract
LAC	Los Angeles County, CA
MTD	mean texture depth
NMDOT	New Mexico Department of Transportation
OGFC	open-graded friction course
PM-CQS-1h	polymer-modified cationic quickset emulsion
PME	polymer-modified emulsion
PME-RAP	polymer-modified emulsified reclaimed asphalt pavement
PMRE	polymer-modified rejuvenating emulsion
PPTA	private preservation treatment applicator
PTL	private testing laboratory
QA/QC	quality assurance/quality control
RAGG	reclaimed asphalt pavement aggregate
RAP	reclaimed asphalt pavement
RAP slurry	reclaimed asphalt pavement in slurry seals
ROW	right-of-way
SBC	San Bernardino County, CA
SN40	skid number value
SSPWC	*Standard Specifications for Public Works Construction*
UNM	University of New Mexico
URC	university research center
WMA	warm-mix asphalt
WTAT	wet track abrasion test

CHAPTER 1. INTRODUCTION

BACKGROUND

Reclaimed asphalt pavement (RAP) use has grown significantly since the oil embargo of the 1970s. The National Asphalt Pavement Association reported over 71 million tons of RAP was used in 2014 (NAPA 2015). RAP was traditionally used in warm-mix asphalt (WMA) and hot-mix asphalt (HMA) construction, including conventional and thin HMA overlays, but there is growing interest among transportation agencies and contractors in using RAP in non-HMA projects, such as chip sealing, slurry sealing, and microsurfacing.

A chip seal is an asphalt binder (commonly an emulsion) sprayed directly to a pavement surface followed by an application of aggregate chips, which are immediately rolled to ensure embedment. A slurry seal is a mixture of well-graded aggregate (e.g., fine sand and mineral filler) and an asphalt emulsion spread over the entire width of a pavement surface with either a squeegee or spreader box attached to the back of a truck. A microsurface is a mixture of crushed, well-graded aggregate, mineral filler (e.g., portland cement), and latex-modified asphalt emulsion spread over the entire width of a pavement surface with either a squeegee or spreader box attached to the back of a truck (Peshkin et al. 2011).

RAP's growth can be attributed to the sustainability and cost benefits of using reclaimed materials, and State and local agencies interested in expanding the use of RAP to non-HMA pavement-preservation treatments hoping to achieve similar benefits. Increased use of RAP in WMA and HMA construction has been tempered by concerns about RAP's impact on pavement durability. RAP has been shown to make pavements stiffer at higher concentrations. Higher RAP concentrations can lead to premature cracking, weathering, and aging, which is why many State and local agencies implemented RAP limits for WMA and HMA construction. Some agencies have strict limits on RAP concentrations in asphalt concrete (AC) mixtures while others allow varying RAP concentrations and instead limit the concentration of binder replacements. Other agencies allow some mixtures to have increased RAP concentrations so long as the blended RAP and virgin AC have the required performance grading.

Using RAP in non-HMA pavement-preservation treatments is not as well known because research on how RAP affects the performance of such treatments is limited. The purpose of this study was to investigate the performance of RAP in non-HMA pavement-preservation treatments to determine whether performance trends similar to those found with WMA and HMA construction projects are evident. This study also documented current practices of using RAP in non-HMA pavement-preservation treatments. The research findings summarized guidance on design criteria, material specifications, construction techniques, costs, inspections, and performance data.

Study Objective

The objective of this study was to document case studies, best practices, applicable tests, treatment costs, and specifications for using RAP in pavement-preservation treatments, such as chip sealing, slurry sealing, and microsurfacing. This report will be useful to pavement-maintenance practitioners as they develop and deploy their pavement-preservation and maintenance programs. This report comprehensively documents the current practices State and local agencies employ for using RAP in pavement-preservation treatments.

Technical Approach

The research in this report was conducted through the following tasks:

1. Hold a kickoff meeting.
2. Document the current practices of using RAP in pavement-preservation treatments with a literature review and conducting practitioner interviews.
3. Develop a work plan outlining the approach to the remaining tasks, including site visits and detailed interviews.
4. Conduct research and produce an interim draft report.
5. Present a webinar describing and summarizing the effort.
6. Publish a TechBrief.
7. Deliver all final documentation, including publishing a final report.

The kickoff meeting was held in October 2016, and the following tasks began immediately thereafter.

Literature Review

Researchers conducted a literature review focusing on transportation agencies' use of RAP in pavement-preservation treatments. The results of the literature review were summarized to indicate the status of using RAP in chip sealing, slurry sealing, and microsurfacing by State and local agencies; existing methodologies for specifying RAP treatments; and the performance of treatments after application. The literature review targeted both domestic and foreign literature derived from studies within the last 5 to 7 yr. The literature review resulted in limited publications identifying using RAP in pavement-preservation treatments but pointed to practitioners whose practices could be evaluated.

Practice Review

To gain a better understanding than was provided from available literature, researchers conducted practitioner interviews and developed case studies for the following agencies and service providers considered prominent leaders in using RAP for pavement-preservation treatments:

- Los Angeles County, CA, (LAC) Department of Public Works.
- San Bernardino County, CA, (SBC) Department of Public Works.
- New Mexico Department of Transportation (NMDOT).
- Private testing laboratory (PTL).
- University research center (URC).
- Private preservation treatment applicator (PPTA).

Researchers coordinated site visits to coincide with access to test sections, active treatment construction, and practitioner availability. This report summarizes the findings of site visits, and case studies are presented for each agency and service provider. The case studies highlight the benefits, risks, alterations, and processes associated with using RAP in chip seals, slurry seals, and microsurfaces. Project successes, failures, and lessons learned are presented as guidance for practitioners considering using RAP in pavement-preservation treatments on their networks.

CHAPTER 2. LITERATURE REVIEW

Using RAP in pavement maintenance, rehabilitation, reconstruction, and new construction projects can help reduce project costs and preserve scarce resources without sacrificing performance. Using RAP in asphalt pavements has been well established for many years, but only recently has it been considered for use in pavement-preservation treatments. This literature review summarizes the findings from several laboratory and field studies.

AGGREGATE RETENTION IN CHIP SEAL

Aggregate retention is a construction and performance issue for chip seals, the causes of which are the existing pavement condition, aggregate-emulsion compatibility, asphalt binder properties (e.g., performance grade, viscosity, chemical properties, polymer content, particle polarity), aggregate-related properties (e.g., dust content, uniformity, quality, quantity, shape, angularity, porosity), and the season in which the construction is carried out (Rahman et al. 2012). Polymer modification improves early aggregate retention, allowing for a reduction in aggregate and emulsion application rates. Dust coating on chips contributes to an insufficient bond between asphalt and aggregate, and using precoated aggregate with 0.5 to 1.5 percent asphalt binder by weight of aggregate improves adhesion. Fine material is either removed as the aggregate is heated in the dryer drum prior to the asphalt coating or the fine material is coated with asphalt and adheres to the larger particles.

Reclaimed asphalt pavement aggregate (RAGG) from an ultrathin, bonded bituminous surface layer on I–70 in Kansas was analyzed along with six other aggregate types. Two asphalt emulsions and the aggregate combinations were evaluated through the ASTM D7000, *Standard Test Method for Sweep Test of Emulsified Asphalt Surface Treatment Samples* (ASTM 2019a). The effect of precoating was evaluated using gravel and limestone aggregates. Rahman et al. (2012) determined that both aggregate and emulsion type play a significant role in mass loss. RAGG with the CRS-1HP emulsion had a significantly lower mass loss compared to the same mix with cationic rapid-setting type 2 polymer modified (CRS-2P) and retained chips like virgin aggregate.

Rahman et al. (2012) concluded that utilizing RAGG in chip seals with the proper emulsion type performs similarly to precoated chip seals with virgin gravel and limestone aggregate.

Full-Depth Reclamation, RAP, and Microsurfacing

A slurry seal contract used RAP materials with full-depth reclamation (FDR) for pavement-maintenance treatments. Heydorn (2014) conducted a study on a 4-acre equipment yard in Richmond, VA, that required a paved surface with a stabilized pavement structure. The company combined soil stabilization with RAP and microsurfacing, resulting in a $250,000 savings when compared to a 6-inch HMA structure, which the company considered an option.

The soil was stabilized with a portland cement content generating a compressive strength of 300 psi. This dosage was spread on the soil, and reclaiming equipment mixed cement and water to a specified soil depth. Once the soil was tilled and mixed, a vibratory compactor was used to achieve the appropriate soil density.

RAP obtained from a previous milling project was placed as a 6-inch base layer on the stabilized soil. The base layer included 1 percent portland cement to increase the initial strength and accelerate curing. A reclaimer mixed the RAP and cement, along with asphalt emulsion, which also increased strength and provided additional particle interlock. Once mixed, the RAP and cement mixture was compacted with a vibratory roller to achieve the appropriate density. The surface was finished with a static steel-wheel roller. Finally, a single-lift, virgin-aggregate microsurface treatment was placed at a rate of 20 lb/sq yd (less than 0.5 inches thick). The project was constructed in less than 2 w in December where, considering weather constraints, an asphalt paving job would take considerably longer.

Typically, for pavement lives over 20 to 25 yr, lifecycle costs for reclamation are 33 to 67 percent less than that of similar HMA construction (Heydorn 2014). Lifecycle costs, construction times, environmental benefits, and performance for both roadways and parking lots make reclamation an attractive option for clients.

Abundance of RAP Spurs New Uses in Preservation Treatments

Despite the increase in allowable RAP percentages in flexible pavement construction, there remains an excess of RAP in urban areas in California. Agencies turned to chip sealing, slurry sealing, and—less commonly—microsurfacing to cost-effectively use reclaimed materials and reduce otherwise growing RAP stockpiles (Updyke and Ruh 2016).

RAGG chip seals installed using polymer-modified rejuvenating emulsions (PMREs) performed well in California since 2008. Additionally, a chip seal composed of RAGG and PG 76-22 tire-rubber-modified asphalt binder was used in the Lake Los Angeles area in 2013. The objective of this project, funded by the California Department of Resources Recycling and Recovery, was to determine whether nonpreheated 0.375-inch and 0.3125-inch RAGG were as compatible as virgin aggregate. Despite a few construction issues, such as variable/high moisture content, RAGG cleanliness on the first day of the project, and adverse weather conditions, the chip seal continues to perform positively. (Updyke and Ruh [2016] did not identify the adverse weather conditions during installation.)

RAGG in slurry seals (RAP slurry) is being used more commonly in southern California (Updyke and Ruh 2016). Even though rolling with a pneumatic tire roller is necessary after placement, the reduction in required virgin asphalt binder content due to residual asphalt in RAGG makes it attractive to agencies. RAGG has a lower emulsion absorption rate than virgin aggregate and is typically encapsulated within the emulsion rather than developing a mechanical bond like with polymer-modified slurry and virgin aggregate.

RAGG in microsurface treatments is less common than RAP slurry but was used in a 2010 project at Soledad Canyon Road and Escondido Canyon Road in the Antelope Valley area of LAC. Both projects performed similarly to virgin aggregate treatments.

RAGG in pavement-preservation treatments is used throughout southern California by State and local agencies. Updyke and Ruh (2016) reported that agencies will revise specifications to increase treatment constructability and maximize benefits (i.e., sustainability and cost savings), after observing project performance over the next few years.

The R Factor: California Project Combines RAP and Tire Rubber in a Cape Seal Treatment

In recent decades, reclaimed materials, such as RAP and tire rubber, have been used in paving applications. Some California agencies own RAP piles and have used them for several applications to stretch their maintenance budgets (Hitti 2014). For example, the LAC Department of Public Works committed to using 100 percent RAGG for all pavement-preservation projects in 2012 and expanded using RAP to 50 percent for all HMA base pavements in 2013.

An example cape seal presented by Hitti (2014) is the two-layer application utilizing hot-applied binder chip seal and a slurry seal with RAP and a tire-rubber emulsion in Bakersfield, CA.

Hot-applied chip seals require high-quality, single-size, precoated aggregate (0.5 to 1 percent asphalt binder by weight of aggregate). Fractionated RAP (i.e., RAGG crushed and screened to 0.375-inch chips) meets the LAC specification for chip gradation and eliminates the need to precoat the aggregate. The tire-rubber asphalt binder application and chip rate variations were tested in the laboratory to determine optimum rates. Hitti (2014) compared virgin and RAGG, each with tire-rubber emulsion and hot-applied asphalt binders, and concluded the nonpreheated RAP chips performed as well as virgin aggregate.

In 2013, chip seals were applied on highly distressed pavements in Bakersfield, CA. A hot-applied asphalt binder with a 15-percent tire-rubber was applied at 0.45 gal/sq yd, then 0.375-inch RAGG was applied, followed by steel wheel rolling and sweeping to finish the application. These chip seals were "cape sealed" by applying emulsified slurry seals with 100 percent RAGG, increasing the amount of RAP used. In general, cape treatments interlock the underlying chips, improve resistance to bottom-up and top-down cracking, and increase pavement smoothness to enhance rider comfort. Kelley (2016) demonstrated with a chip seal of 100 percent RAP that both the coarse and fine RAP fractions can be used in the same project.

Scrub Seal Using RAP, Premium Emulsion Serves Busy Interstate

A scrub seal is a pavement-preservation treatment where an asphalt emulsion is applied to a pavement surface followed quickly by a broom-scrubber apparatus that pushes the emulsion into surface cracks and voids. The scrubbing is followed by an aggregate application like a chip-seal process. Brooming to remove excess aggregate completes the application.

A scrub seal with 100-percent RAGG and a PMRE was applied on I–10 and performed similarly to virgin materials (FP^2 2011). The proprietary PMRE has been used in other maintenance applications, such as crack sealing, tack coating, fog sealing, and scrub sealing (FP^2 2011).

The California Department of Transportation (Caltrans) determined that hauling RAP millings to their distant yard for storage was not cost effective and that the millings could be converted onsite to a useable product meeting the Caltrans chip specification (FP^2 2011). Crushing and screening resulted in fractionated RAP (i.e., 0.3125- and 0.375-inch RAGG) for chip or scrub seals and RAGG for slurry seals (FP^2 2011).

The scrub seal was applied with 0.375-inch chips but was outperformed by a later application of 0.3125-inch chips. The RAP proved to be workable, and the aggregate's high-quality precoating reduced the amount of emulsion required (FP^2 2011). The RAGG was highly compatible with the emulsion (i.e., there was rapid adhesion and setting), allowing traffic to operate within 4 h of application. The RAP chips provided a dark background that increased delineation after pavement markings were applied.

A RAP slurry with the potential to reduce costs for projects was also considered in Caltrans district 8's slurry-seal program. Cost savings came from the residual asphalt content in the RAP fine particles reducing the emulsion content required in the mix by approximately 20 percent (FP^2 2011).

Developing Statewide Standard Practices for the Use of Asphalt Millings for Maintenance Projects in New Mexico

Tarefder and Ahmad (2017) conducted a feasibility analysis to determine the best uses for asphalt millings (i.e. RAP) in different pavement-maintenance projects throughout New Mexico. Literature reviews, NMDOT district surveys, and field-performance observations were used to develop a guide. NMDOT district surveys identified chip sealing as the predominant maintenance procedure, while sand sealing, scrub sealing, and microsurfacing were rarely used. Tarefder and Ahmad (2017) discouraged microsurfacing because they believed RAP substitution was not feasible. In addition to chip seals, asphalt millings were blended with an asphalt emulsion into a patching material used to fill potholes.

To summarize best practices in selecting pavements suitable for a chip seal, local and national recommendations were analyzed. Locally, each NMDOT district that responded to surveys used different distress combinations to select a chip seal. Tarefder and Ahmad (2017) found pavements with low to moderate traffic volume and low to moderate cracking, rutting, raveling, bleeding, and potholing—which must be patched prior to sealing—suitable for chip seals. Recently overlaid pavements or those with oxidization, a nonuniform surface, or nondefined shoulder sections were also good candidates for chip seals.

Material selection had a significant impact on treatment performance, so locally available aggregate and binders were studied to determine best practices for material selection. Tarefdir and Ahmad (2017) summarized the following common practices identified by several State and local agencies:

- Aggregate size should be between 0.375 and 0.5 inches.
- Aggregate application rate should be between 25 and 30 lb/sq yd.
- Asphalt binder application rate should be between 0.15 and 0.5 gal/sq yd.
- Fines content should not exceed 2 percent (5 percent if polymer-modified asphalt binder is used).
- Flat and elongated particles should not exceed 30 percent.
- Chips should be washed or screened to remove dust prior to placement.
- Aggregate should be dampened for dust control and bonding enhancement.
- Aggregate should be precoated if the binder is hot-applied.
- Asphalt millings (i.e., RAP) should be used to reduce initial construction cost and for sustainability.
- Cubical aggregates are preferred.

- Recommended binder types include CRS-2P, high-float emulsion with polymer (HFE100P), polymer-modified emulsion (PME), high-modulus asphalt rubber, and rubberized emulsion.
- PME should be used for improved workability.
- Aggregate, binder, and mix should undergo quality assurance/quality control (QA/QC) and performance tests.

QA/QC is essential during construction to avoid early failure of the surface treatment, including bleeding or loose chips becoming airborne and damaging vehicle windshields. Similar to aggregate and binder properties, Tarefder and Ahmad (2017) conducted a review to determine the best practices for construction QA/QC and inspection and recommended the following:

- Emulsion temperature should be between 125 and 185°F.
- Air temperature should be between 60 and 105°F.
- Surface temperature should be between 60 and 130°F.
- Temperature within 24 h should be 39°F and above.
- Humidity should be 50 percent or lower.
- Construction season may vary based on climate and locations (e.g., New Mexico chip seals are placed between April and September).
- Test strip should be approximately 400 ft long.
- Calibration checks are required for chip and emulsion application rates.
- The pavement surface should be cleaned prior to applying the chip seal.
- Cracks wider than 0.375 inch should be sealed at least 6 mo (or one season) prior to applying the chip seal.
- A tack coat is not required prior to applying the chip seal.
- Potholes should be repaired prior to applying the chip seal.
- The pavement surface should be blade patched, if needed, one season prior to applying the chip seal.
- Any vegetation on the pavement surface (including the shoulder) should be removed.
- Traffic should be controlled in accordance with applicable traffic-control standards.
- The pavement surface should be rolled at least three times with a pneumatic tire at 5 mph with a pressure between 45 and 90 psi.
- The surface should be broomed prior to opening to traffic.
- The application rates should be controlled through checks.
- Immediate embedment depth must be at least 50 percent.
- Field tests should be carried out if necessary (e.g., ball penetrometer, sand patch, and falling-weight deflectometer [FWD]).

RAP is milled, crushed, and processed through 0.375- and 0.5-inch screens and moved to its stockpile by conveyor belts. RAP chip seals have performed positively, but long-term performance has yet to be observed. Field inspections 1 yr after construction showed virtually no distresses other than loose aggregate. The surface oxidation seemed low, which suggests a longer service life for the treatment. The international roughness index dropped from 175 inches per mi prior to treatment to 128 inches per mi after treatment. The treatment also caused the present serviceability index to increase from 2.52 to 2.93. Surveys indicated that chip seal thicknesses throughout New Mexico vary from 0.375 to 1 inch, and their service life varies from 3 to 10 yr.

Tarefder and Ahmad (2017) compared a chip seal with RAP to a chip seal with virgin aggregate. Each test and its corresponding result are as follows:

- Sand patch test—for chip seals with RAP, the mean texture depth (MTD) was slightly higher than chip seals with virgin aggregate.
- Skid resistance test using a British pendulum—chip seals with virgin aggregate and those with asphalt millings showed no significant difference.
- Direct shear test—chip seals with virgin aggregate and those with asphalt millings showed no significant difference.
- Sweep test—though a higher chip retention was observed when a lower percentage of chips passing the No. 4 sieve was used, the test was still ongoing and no conclusions were drawn.

A lifecycle cost analysis showed asphalt millings in chip seals cost less and perform similarly compared to chip seals with virgin aggregate (Tarefder and Ahmad 2017). Chip seals with asphalt millings were 23 to 37 percent more cost effective (varies among districts) than chip seals with virgin aggregate.

NMDOT rarely used sand seals and scrub seals; however, Tarefder and Ahmad (2017) referred to work done in California by contractors applying a sand seal and using RAP for a scrub seal. Typically, a high-float polymer-modified emulsion HFE90P is used for both seals with an application rate of 0.4 and between 0.2 and 0.25 gal/sq yd, respectively. Scrub seals use a 0.375-inch maximum aggregate size and an application rate of approximately 20 lb/sq yd.

On the site of the sand seal, an open-graded friction course (OGFC) was applied to the pavement 8 yr prior. Tarefder and Ahmad (2017) described the pavement condition prior to the sand seal as missing aggregate and having wide cracks throughout the surface. An HFE100P and 0.25-inch maximum aggregate size millings were used for this sand seal. The asphalt millings were significantly aged and included some uncoated particles. The emulsion spread rate required several adjustments until a rate of 0.28 gal/sq yd was selected. Similarly, it was necessary to adjust the rate of the aggregate to address bleeding during compaction. The final RAP-sand rate was 17 lb/sq yd. The pavement surface was then compacted using three to four passes with a pneumatic roller and one pass with a steel roller for finishing. The pavement surface was broomed 1 d after construction to complete the process. The pavement surface deteriorated significantly 1 yr after construction. Some distresses found during the inspection were severe raveling, aging (i.e., oxidation) of the asphalt binder, bleeding, rutting, and potholing. Approximately 50 percent of the preexisting cracks propagated to the surface (Tarefder and Ahmad 2017).

Tarefder and Ahmad (2017) concluded that asphalt millings can be used for maintenance projects when applied to good candidate pavements, using proper construction techniques, and measuring quality according to established specifications. Asphalt millings in chip seals performed well throughout the first stages of their service life, while sand seals did not perform as expected after 1 yr, mainly due to varying blending proportions during construction and poor pretreatment condition of the pavement. These pavement sections must be analyzed throughout their design life to evaluate their performance.

Summary

Budget constraints shifted the focus of highway funds away from less cost-effective options toward pavement preservation. RAP is readily available from stockpiles or obtained and converted at a project site. Hauling asphalt millings, virgin aggregate, and asphalt binder are costly compared to using materials available onsite. Using RAP reduces the need for virgin aggregate without sacrificing pavement performance—in certain cases, performance improved—which justifies and encourages increased RAP use.

CHAPTER 3. SUMMARY OF PRACTICE REVIEW

Based on practitioner interviews, case studies were developed for the following agencies and service providers considered prominent leaders in using RAP for pavement-preservation treatments:

- LAC Department of Public Works.
- SBC Department of Public Works.
- NMDOT.
- PTL.
- URC.
- PPTA.

The case study participants represent owners that have implemented RAP treatments on their roadways, suppliers that have designed treatment systems to meet common design parameters, and contractors that have processed materials and built treatments that meet owner and/or agency specifications. Participants shared their motivations for using RAP treatments, their experimentation process to refine them, their concerns where limitations exist, and their conclusions from the applications. Table 1 summarizes the topics of interest addressed in each case study.

Table 1. Research topics investigated by each agency or service provider.

Research Topic	Agency/Service Provider					
	LAC	SBC	NMDOT	PTL	URC	PPTA
Cultural discussions leading to using RAP in surface treatments	*	*	*	—	—	—
Cost implications of using RAP in surface treatments	*	*	*	*	*	*
Modifications to accommodate RAP in chip sealing, slurry sealing, and microsurfacing	*	*	*	*	*	*
RAP processing requirements (e.g., fractionation, drying, storing, and crushing)	—	*	*	*	*	*
Specifications	*	*	—	*	—	*
Construction methods, mix designs, and inspection techniques	*	*	*	*	*	*
Mix design testing modifications	*	—	—	*	*	*
Potential binder reductions	—	—	—	*	*	—
Performance characteristics	*	*	*	—	*	—
Recorded surface characteristics	*	*	—	—	*	—
Availability of pavement-performance data	*	*	*	*	*	*
Performance of RAP surface treatments	*	*	*	—	*	—
Adhesion of particles to new binders	*	*	*	*	*	*
Surface characteristics (e.g., texture, skid resistance, noise)	*	*	*	—	*	—
Premature aging or cracking	*	*	*	—	*	—
Delamination	*	*	*	*	*	—
Needs and next steps	*	*	*	*	*	*

*Topic investigated.
—Topic not investigated.

CASE STUDY: LAC DEPARTMENT OF PUBLIC WORKS

Fully Implemented RAP Treatments on County Roads

Background

Located in southern California and home to over 10 million people, LAC is the most populous county in the United States (figure 1-A). Although LAC encompasses several municipalities that operate their own transportation networks, it still owns and operates 7,400 lane-miles of roadway (figure 1-B) (LAC 2018a).

Source: FHWA.

A. LAC is located in southern California.

Source: FHWA.

B. LAC encompasses several southern California municipalities.

Figure 1. Maps. Greater Los Angeles area.

LAC used numerous pavement-preservation treatments, including crack filling, patching, milling, chip sealing (both conventional and rejuvenating emulsions), scrub sealing, slurry sealing, microsurfacing, asphalt rubber and aggregate chip seal, flush sealing, and asphalt overlay. LAC used a $4.7 million annual job-order contract (JOC) to deliver indefinite delivery/indefinite quantity (ID/IQ) preservation projects, which included many of these treatments, across the county.

A JOC is a type of ID/IQ contract that uses a construction-task catalogue with prepriced work items and descriptions. Contractors add adjustment factors (i.e., markup rates) to the prepriced work items, and the contract is awarded by competitive bidding to the lowest responsive bidder determined by their markup rate (Hendrickson 2019). LAC developed the unit price estimates and worked with the preservation industry to verify cost relationships for items were appropriate for the work expected. Multiple prices were developed for some items with quantity ranges that anticipate factors such as lower efficiency for lower-quantity work orders.[1] Contractors submit bids on the entire preservation catalog using a single multiplier applied to each unit price. The multiplier may be more or less than 1 depending on the bidder's anticipated cost to perform the work. The bidder with the lowest multiplier and the lowest subsequent contract value is awarded the contract. A benefit to using the JOC is that an agency can have a single on-call contract to implement all the preservation work during the cycle, which allows them to manage the budget and schedule the work with the contractor months ahead. Although unbalanced bidding is difficult to detect and prevent in ID/IQ contracts, unit price relationships being fixed within the JOC means unbalanced bidding is generally not possible.

Cultural Discussions Leading to Using RAP in Surface Treatments

While increasing their focus on sustainable practices, LAC began RAP treatments on trial pavements sections around 2009. Both RAP chip seals and RAP slurry seals were applied and provided equivalent performance to virgin treatments. As shown in figure 2, LAC published a sustainability brochure to communicate to the public the importance that pavement preservation plays in their overall sustainability program (LAC 2018a).

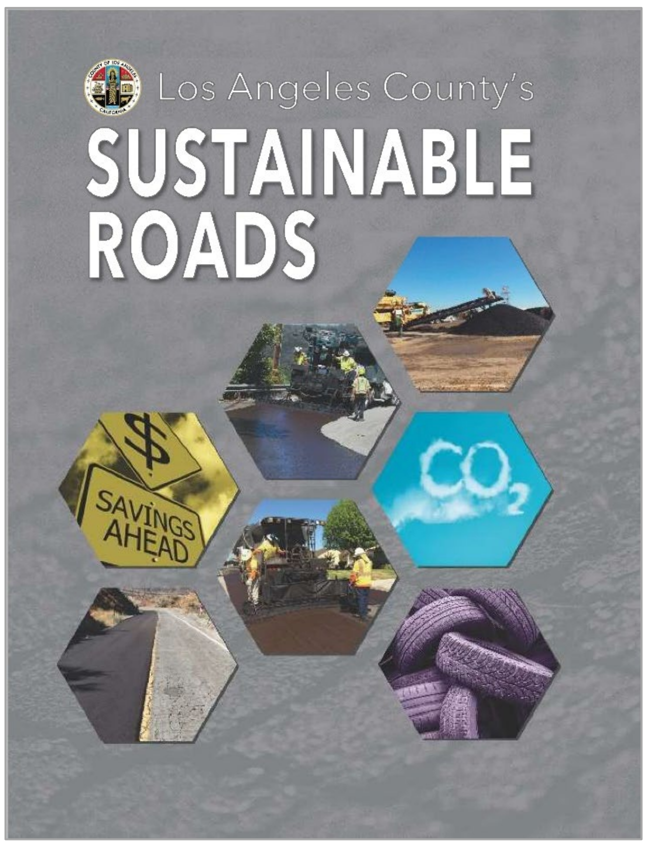

Figure 2. Graphic. LAC sustainability brochure.

[1]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

According to the brochure, LAC undertook the following actions to develop more sustainable pavement-preservation practices:

- Preserve—preservation mitigates the need for more costly treatments by proactively extending pavement service life. For roadways in good condition, preservation ensures they stay that way. For roadways in fair or poor condition, preservation inhibits the deterioration from progressing until funding is available for more permanent repairs. Without preservation, roadways would continue to deteriorate, adversely affecting rider safety, rider comfort, and repair costs.

- Reuse—rather than throw away old roadway material, the material is reused to treat the pavement. Similarly, old tires are crumbled and used in new roadways to make them quieter and last longer. By repurposing used materials, natural resources are retained and landfill deposition is reduced.

- Fortify—as population and traffic grow, roadways need to be rebuilt stronger. Past practice was to dig up and replace the entire pavement. In extreme cases, base material and soil were also removed and replaced. This resulted in increased construction time, air pollution, waste, and costs. Current practice is to fortify existing material in place by adding components like cement to strengthen the existing base material and oil-based emulsions to rejuvenate old pavement. By fortifying materials in place, significant environmental and cost savings are achieved (LAC 2018a).

LAC's sustainability efforts resulted in the following (LAC 2018a):

- $52 million in cost savings.
- 84 percent reduction in greenhouse gasses.
- 80 percent reduction in energy consumption.
- 418,000 cu yd reduction in landfill deposition.

LAC advocates using preservation strategies as a whole-life approach to pavement sustainability, applying treatments to either maintain good conditions or to inhibits the deterioration from progressing in fair and poor pavements. While FDR played a significant role in achieving the fortify component of LAC's sustainability efforts, the reuse component referenced RAP and scrap tire rubber use in pavement-preservation treatments.

The brochure summarized LAC's commitment to sustainability. Over the years since RAP treatments were implemented, LAC's commitment strengthened to require slurry sealing using RAGG, while chip sealing, scrub sealing, and microsurfacing permitted using RAP at the discretion of the contractor. LAC's RAP pavement-preservation treatments were applied to 152 lane-miles of roadway in 2018. Preserving these roadways comprised 53 percent of the lane-miles covered in 2018 and accounted for 35 percent of LAC's pavement-program budget.[2]

[2]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

Cost Implications of Using RAP in Surface Treatments

Relative unit prices are listed in LAC's JOC and are summarized in table 2 and table 3, noting that RAP materials can be substituted for virgin materials with no change in price. The awarded contract for this cycle had a contractor bid factor of 0.82, reducing the unit prices by 18 percent from their value assigned by LAC. Even though LAC provided unit prices for virgin slurry seal and polymer-modified emulsified reclaimed asphalt pavement (PME-RAP) slurry, slurry seal was chosen exclusively for neighborhood roadways. LAC designated higher unit prices for PME-RAP slurry than virgin aggregate based on locally contracted prices from the previous few years. LAC reported that the PME-RAP prices will be adjusted to equal virgin aggregate prices for the next contract.[3] According to LAC officials, most work orders issued are for PME-RAP slurry quantities higher than 1,000 tons.

Table 2. LAC JOC unit prices for preservation treatments per ton.

Treatment Type	120–500 Tons (U.S. Dollars)	500–1,000 Tons (U.S. Dollars)	1,000–2,000 Tons (U.S. Dollars)	>2,000 Tons (U.S. Dollars)
Microsurface Type II	—	280	250	200
Microsurface Type III	—	300	265	215
Slurry seal	300	275	250	250
PME-RAP slurry	340	300	290	290

—No data.

Table 3. LAC JOC unit prices for preservation treatments per 1,000 sq yd.

Treatment Type	25,000–50,000 sq yd (U.S. Dollars)	50,000–150,000 sq yd (U.S. Dollars)	>150,000 sq yd (U.S. Dollars)
PME chip	3.40	3.20	2.80
PMRE chip	3.60	3.40	3.00
Scrub seal	4.20	4.00	3.80

Specifications

LAC references the *Standard Specifications for Public Works Construction* (SSPWC) as the source for most work performed under the JOC; however, there are alterations included as special provisions that supersede the SSPWC (BNI 2018). Special provisions are included that modify the standard requirements for chip, scrub, and slurry sealing and microsurfacing to include RAP materials (LAC 2018b).

Chip Seals and Scrub Seals

For chip seals and scrub seals, the following excerpt from the JOC permits replacing virgin aggregate with RAP:

[3]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

906-2.2.2 Reclaimed Asphalt Pavement (RAP) Screenings. The contractor may, at its option, furnish and apply screenings produced from RAP. RAP screenings shall be produced by crushing asphalt concrete pavement, be free of detrimental quantities of deleterious materials, and have a minimum sand equivalent of 80 when tested in accordance with California Test 217. Conformance to the requirements shown in table 200-1.2.2.1 of the SSPWC is not required. Grading shall conform to the requirements shown in table 200-1.2.2.2. (LAC 2018b, p. TR-25)

Table 200-1.2.2.1 of the SSPWC establishes aggregate quality requirements for aggregate screenings or chips used for chip seals. The minimum cleanliness value for RAP is 80—the same as for virgin chips—and the maximum requirement for percentage wear at 500 revolutions is 45. Film stripping (in accordance with California Test Method (CTM) 302, *Method of Test for Film Stripping* [Caltrans 2014a]) and durability (in accordance with CTM 229, *Method of Test for Durability Index* [Caltrans 2011]) is waived. RAP chip gradation is required to conform to virgin chip grading as specified by the SSPWC (table 4) (BNI 2018). As shown in figure 3, medium fine gradation is the most commonly designated size for LAC chip and scrub seals.[4]

Table 4. SSPWC chip grading requirements for RAP chip seals.

Sieve Size	Medium Fine 5/16 Inch × No. 8 (8.0 × 2.36 mm) Percent Passing Sieve
⅜ inch (9.50 mm)	100
No. 4 (4.75 mm)	0–50
No. 8 (2.36 mm)	0–15
No. 16 (1.18 mm)	0–5
No. 30 (600 µm)	0–3
No. 200 (75 µm)	0–2

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.

[4]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

Source: FHWA.

Figure 3. Photo. Surface texture of a RAP scrub seal applied to a milled surface.

Slurry Seals

LAC has a special provision within their JOC specifying the requirements for RAP slurry seals: Section 908—Polymer Modified Emulsified Asphalt–Reclaimed Asphalt Pavement Aggregate Slurry Seal (LAC 2018b). To compare the requirements for RAP and virgin slurry seals, Section 203-5—Slurry Seal from the SSPWC was reviewed (BNI 2018). Both specifications require the same polymer-modified cationic quickset emulsion (PM-CQS-1h) for RAP and virgin slurry seals. As shown in table 5, the emulsion content requirement for virgin slurry seals is significantly higher than for RAP slurry seals; however, when the minimum residual asphalt content was observed, the RAP slurry seal requirement was higher than for virgin slurry seals (LAC 2018b; BNI 2018). The LAC RAP slurry seal special provision is found in appendix A.

Table 5. Requirements for RAP and virgin slurry seals.

Component	Characteristic	Test Method	RAP Slurry Seal Requirements	Virgin Type II Slurry Seal Requirements
Asphalt	Slurry seal emulsion, percent by weight of dry RAGG	—	9.0–14.0	14.0–18.0
	Minimum residual asphalt, percent	ASTM D6307 (ASTM 2019b) or CTM 382 (Caltrans 2014b)	11.0	7.5
Aggregate	Percentage wear, 500 revolutions, maximum percent	ASTM C131 (ASTM 2020)	35.0	40.0
	Sand equivalent, minimum	ASTM D2419 (ASTM 2014)	60.0	55.0
	Soundness (five cycles), maximum percent	ASTM C88 (ASTM 2018)	15.0	15.0
	Durability, minimum	CTM 229 (Caltrans 2011)	55.0	N/A
Mixture	WTAT, maximum weight loss (g/sq ft)	ASTM D3910 (ASTM 2015b)	50.0	60.0
	Consistency test (mm)	ASTM D3910 (ASTM 2015b)	30.0 (maximum)	20.0–40.0
	Extraction test (calculated emulsion content, percent)	ASTM D6307 (ASTM 2019b) or CTM 382 (Caltrans 2014b)	±1 percent of mix design	±1 percent of mix design
	Water content (percent of dry RAGG weight)	—	<25.0	<25.0

1 mm = 0.039 inches.
—No test method.
N/A = not applicable; WTAT = wet track abrasion test.

LAC requires RAGG quality be slightly higher than virgin aggregate. For instance, the LAC JOC specification 908-2.2 limits the maximum percentage wear requirement to 5 percent less for RAGG and requires a sand equivalent value for RAP 5 percent higher than virgin aggregates used in slurry seals (LAC 2018b). Additionally, mixture requirements for RAP slurry seals are more stringent in material quality. A higher standard is demonstrated in a lower wet track abrasion test (WTAT) loss value and a lower consistency value.

In the PME-RAP special provision within the JOC, aggregate grading bands are expressed for both unextracted and extracted RAGG. As listed in table 6, the extracted RAGG grading is required to match the SSPWC Type II grading requirement for virgin aggregate. The unextracted RAGG grading band more coarse than the extracted RAGG grading, meaning the RAP material contains conglomerates of finer particles that would break down into smaller, more discrete particles after extraction.

Table 6. LAC RAP slurry seal grading requirements and combined aggregate passing sieves.

Requirement	Unextracted RAGG (Percent)	Extracted RAGG (Percent)	SSPWC Type II Slurry (Percent)
⅜ inch (9.50 mm)	100	100	100
No. 4 (4.74 mm)	90–100	90–100	90–100
No. 8 (2.36 mm)	60–90	65–90	65–90
No. 16 (1.18 mm)	35–60	45–70	45–70
No. 30 (600 µm)	23–45	30–50	30–50
No. 50 (300 µm)	12–30	18–36	18–36
No. 100 (150 µm)	5–20	10–24	10–24
No. 200 (75 µm)	0.5–10	5–15	5–15

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.
Note: SSPWC Type II Slurry requirement referenced from section 203-5.3.2 (BNI 2018).

Like virgin slurry mixtures, a continuous-flow mixer is required for RAP slurry application. LAC requires a contractor use at least two applicators to maintain continuous operation throughout the day. In addition, RAP slurry application requires rolling with a pneumatic tire roller a minimum of three passes. LAC staff report the roller seats the mixture and helps the emulsion bind to the RAP particles more effectively. Rolling takes place approximately 4 h after application and after the emulsion has broken but prior to opening the roadway to traffic.

LAC acknowledges that multiple vendors helped develop a workable RAP slurry seal specification (figure 4). After significant experience with the treatment design and observed performance, RAP slurry seals have become the most commonly used pavement-preservation treatment on residential roadways in LAC.[5]

[5]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

Source: FHWA.

Figure 4. Photo. RAP slurry seal applied on a residential roadway in LAC.

Microsurfaces

LAC contractors apply PME-RAP slurry seals more often than they use RAP materials as a substitute for virgin aggregate in microsurface. As shown in figure 5, a microsurface is typically applied to arterial roadways with higher traffic volumes than residential roadways. Table 7 shows the grading bands for unextracted RAP and extracted RAGG to be used in microsurface in contrast to the virgin aggregate SSPWC Type II microsurface (BNI 2018). A higher percent passing for extracted RAGG is permitted by the specification on No. 16 through No. 100 screens, while the percent passing the No. 200 screen is similar to the virgin aggregate requirement.

Source: FHWA.

Figure 5. Photo. RAP microsurface on an arterial roadway.

Table 7. LAC RAP microsurface grading requirements and combined aggregate passing sieves.

Requirement	Unextracted (Percent)	Extracted RAGG (Percent)	SSPWC Type II (Percent)
⅜ inch (9.50 mm)	100	100	100
No. 4 (4.74 mm)	95–100	95–100	90–100
No. 8 (2.36 mm)	65–85	70–90	65–90
No. 16 (1.18 mm)	35–60	50–75	45–70
No. 30 (600 µm)	18–38	35–55	30–50
No. 50 (300 µm)	8–20	22–40	18–36
No. 100 (150 µm)	5–20	13–38	10–24
No. 200 (75 µm)	2–12	5–15	5–15
Residual Asphalt Content (ASTM 6307 [(ASTM 2019b])	—	6.5 percent minimum	—

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.
—No data.
Note: SSPWC Type II requirement referenced from section 203-5.3.2 (BNI 2018).

As shown in table 8, residual asphalt content requirements are higher for RAP microsurfaces than virgin aggregate. Aggregate quality requirements for RAP microsurfaces are identical to those of PME-RAP slurry seals. Mixture requirements for RAP microsurfaces, such as mix time and WTAT loss results, are the same as those for virgin aggregate microsurfaces.

Table 8. LAC requirements for RAP and virgin microsurfaces.

Component	Characteristic	Test Method	RAP Microsurface Requirements	Virgin Microsurface Requirements
Asphalt	Emulsified asphalt, percent by weight of dry RAGG	—	10.0–14.0	—
	Minimum residual asphalt, percent	ASTM D6307 (ASTM 2019b) or CTM 382 (Caltrans 2014b)	12.5	Type II: 5.5–10.5 Type III: 6.5–10.5
Aggregate	Percentage wear, 500 revolutions, maximum percent	ASTM C131 (ASTM 2020)	35.0	35.0
	Sand equivalent, minimum value	ASTM D2419 (ASTM 2014)	60.0	65.0
	Soundness (five cycles), maximum percent	ASTM C88 (ASTM 2018)	15.0	N/A
	Durability, minimum percent	CTM 229 (Caltrans 2011)	55.0	52.0
Mixture	WTAT loss g/sq ft (g/sq m) 1-hr soak 6-d soak	ISSA TB-100 (ISSA 2018a)	60.0 g/sq ft (646.0 g/sq m) 75.0 g/sq ft (810.0 g/sq m)	75.0 g/sq ft (810.0 g/sq m)
	Slurry seal consistency (mm)	ISSA TB-106 (ISSA 2015)	30 maximum	N/A
	Mix time	ISSA TB-113 (ISSA 2017)	Controllable to 120-s minimum at the maximum expected air temperature at the site during application	Controllable to 120-s minimum at the maximum expected air temperature at the site during application

1 mm = 0.039 inches; 1 m = 3.281 ft.
—No test method.
ISSA = International Slurry Seal Association; N/A = not applicable.

The LAC specification for microsurface mix design requires the WTAT loss patty and lateral displacement strip be hand rolled with a rolling pin after drying to the touch. Hand rolling compacts the specimen prior to testing similar to how the materials are rolled in the field (LAC 2018b).

Inspection and Testing Processes

LAC employees inspect all pavement-preservation projects. In addition to visual inspection of the materials and methods used during placement, the JOC PME-RAP slurry acceptance specification also requires that a WTAT be conducted from production materials and transported to the LAC laboratory for testing.

As shown in table 9, payment reduction occurs if field sample testing shows greater than 50 g/sq ft of loss during the WTAT. The same payment reduction methodology applies to virgin aggregate slurry seals. The JOC specification provides for third-party testing to resolve any disputes over the test-results-based payment.

Table 9. Payment reduction based on WTAT results for PME-RAP slurry.

WTAT Loss (g/sq ft [g/sq m])	Payment Reduction (Percent)
0.0–50.0 (0.0–540.0)	0
50.1–60.0 (540.1–650.0)	5
60.1–70.0 (650.1–750.0)	15
70.1–80.0 (750.1–860.0)	30
80.1–99.0 (860.1–1,070.0)	70
99.1 or greater (1,070.1 or greater)	100

1 m = 3.281 ft.

Note: Slurry seal with WTAT loss greater than 99.1 g/sq m (1,070.1 g/sq ft) shall be removed to the satisfaction of the engineer.

Performance Characteristics

After switching from virgin aggregate to predominantly using RAP in pavement-preservation treatments, LAC employees monitored their pavement ratings at the network level to determine what impact using RAP had on pavement-performance expectations. LAC staff pointed to the performance of two similar neighborhoods where nearly equivalent pavement-preservation treatments were applied—except one used RAP and the other did not. The Arroyo and Dunton Drive neighborhood was treated with virgin aggregate in 2010. The Gunn and Du Page Avenue neighborhood was treated with RAGG in 2012. LAC staff evaluated both neighborhoods 2 yr after application and both showed equivalent performance. Figure 6 and figure 7 show the pavement condition maps 9 and 7 yr after application, respectively.

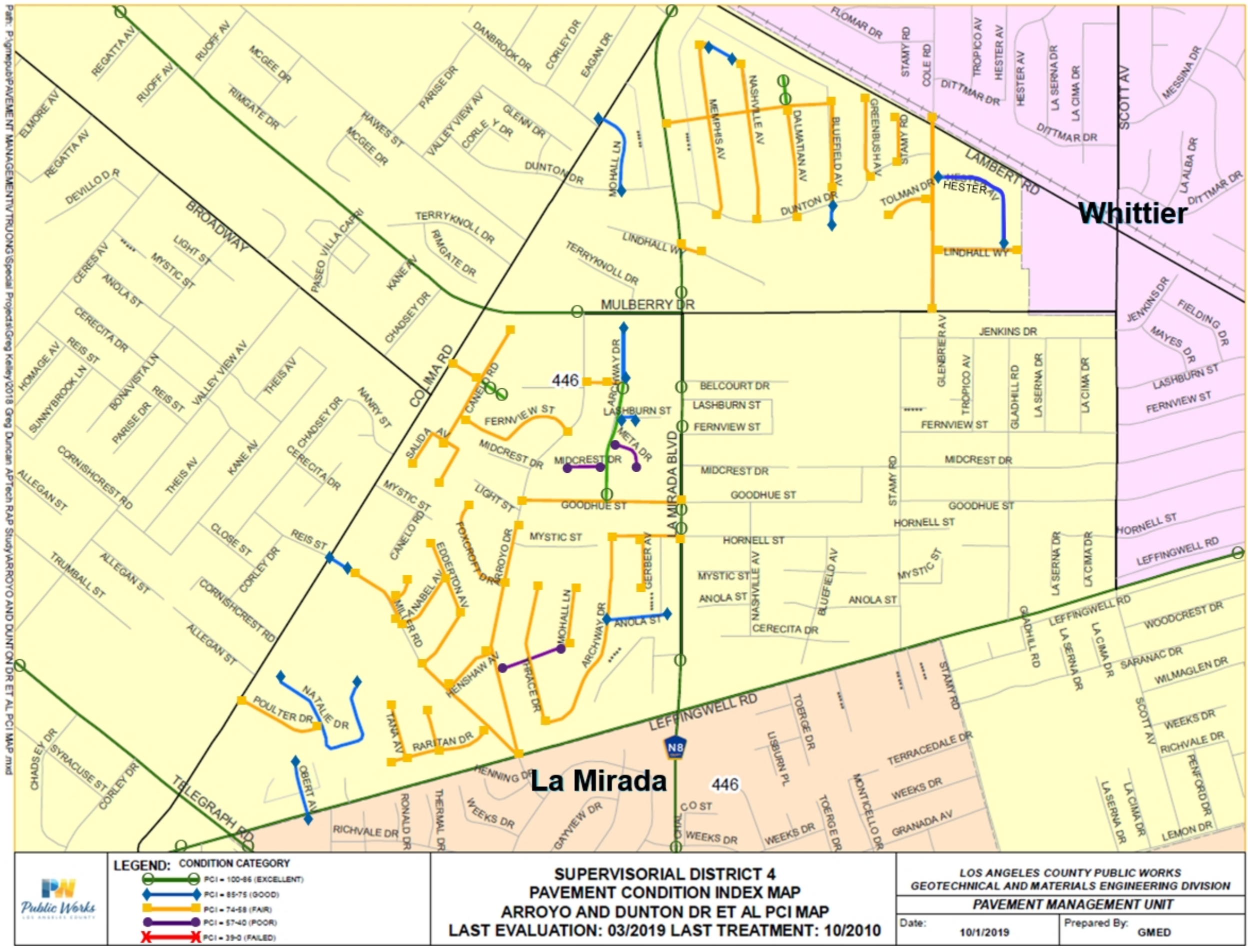

Figure 6. Map. LAC pavement condition index map of the Arroyo and Dunton Drive neighborhood.

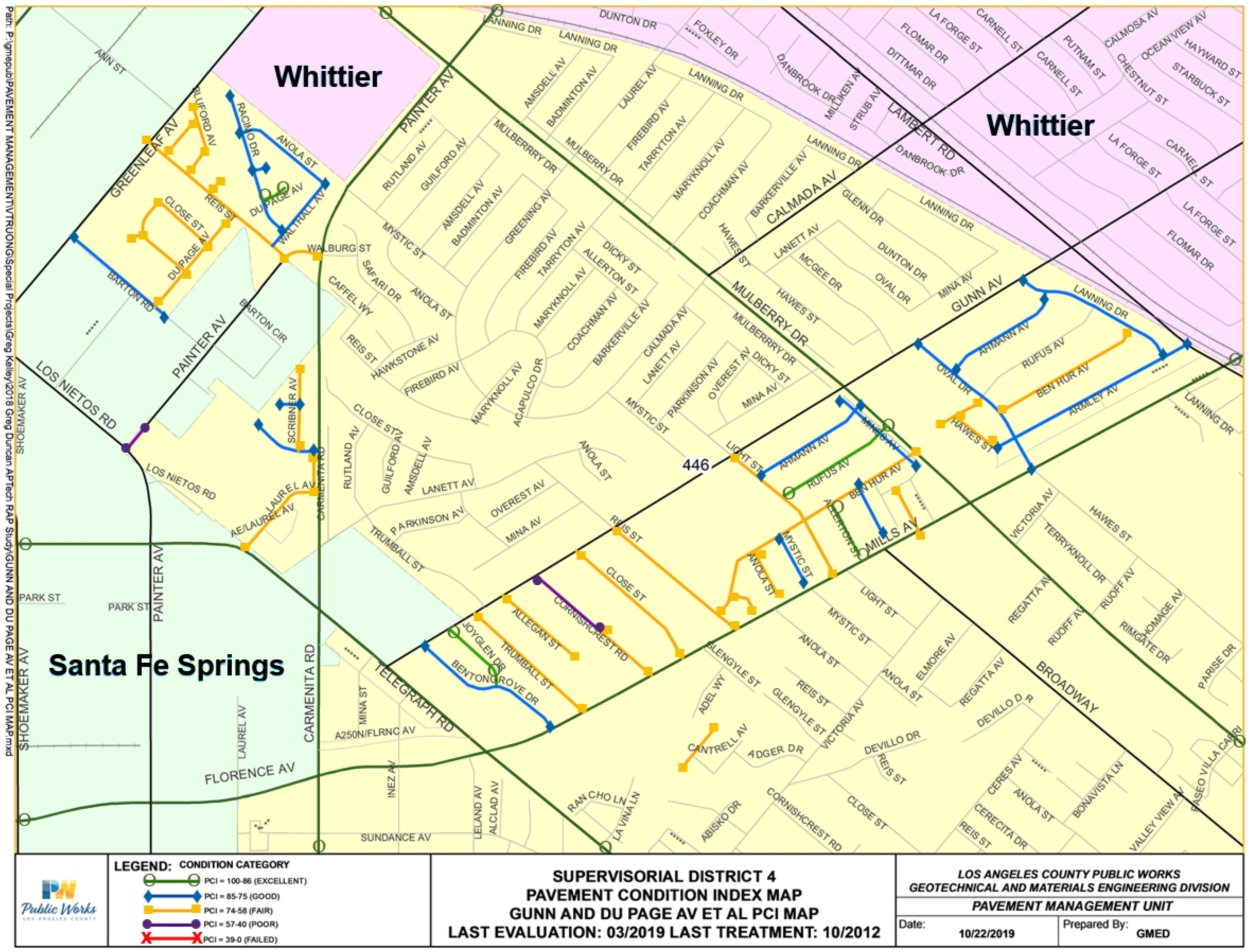

Figure 7. Map. LAC pavement condition index map of the Gunn and Du Page Avenue neighborhood.

The most common treatment combination applied in these neighborhoods consisted of micromilling less than 1 inch deep from the existing surface, applying a 0.3125-inch RAP scrub seal, and then applying a RAP slurry seal. In the Sinaloa Avenue neighborhood during a site visit in 2018, LAC staff observed pavement distress, including low-severity block cracking and minor bleeding, as shown in figure 8 and figure 9, respectively. LAC employees described these distresses as consistent with those observed in virgin treatment sections of the same age. Because the treatments applied to the roadways were robust, LAC employees believed the cracking was reflecting through the scrub and slurry seals and the minor bleeding was excess binder from the scrub seal seeping through the slurry seal. LAC employees determined neither of these distresses resulted from RAGG use.[6]

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[6]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

Source: FHWA.

Figure 8. Photo. Four-year-old slurry seal with low-severity block cracking.

Source: FHWA.

Figure 9. Photo. Four-year-old slurry seal with minor bleeding.

Conclusion

Sustainability is a prominent goal for the LAC pavement program. LAC's switch from conventional to sustainable practices saved over $52 million and reduced greenhouse gases substantially. Since 2009, LAC's RAP use has grown such that, in 2018, approximately 35 percent of LAC's annual pavement-program budget was spent on RAP pavement-preservation treatments. Routinely using RAP improved construction specifications and practices, including requiring three passes with a pneumatic-tire roller on PME-RAP slurry seals and procurement through a JOC. LAC adopted higher unit prices for PME-RAP slurry seals to encourage growth in the industry and compensate vendors for increased handling and rolling requirements.

LAC is satisfied with the performance of RAP and evaluated distress data after multiple applications to determine RAP treatments performed equally to applications with virgin materials. LAC will continue using RAP in their pavement-preservation treatments and specify using RAP in pavement-preservation treatments where it is now considered an optional alternative.

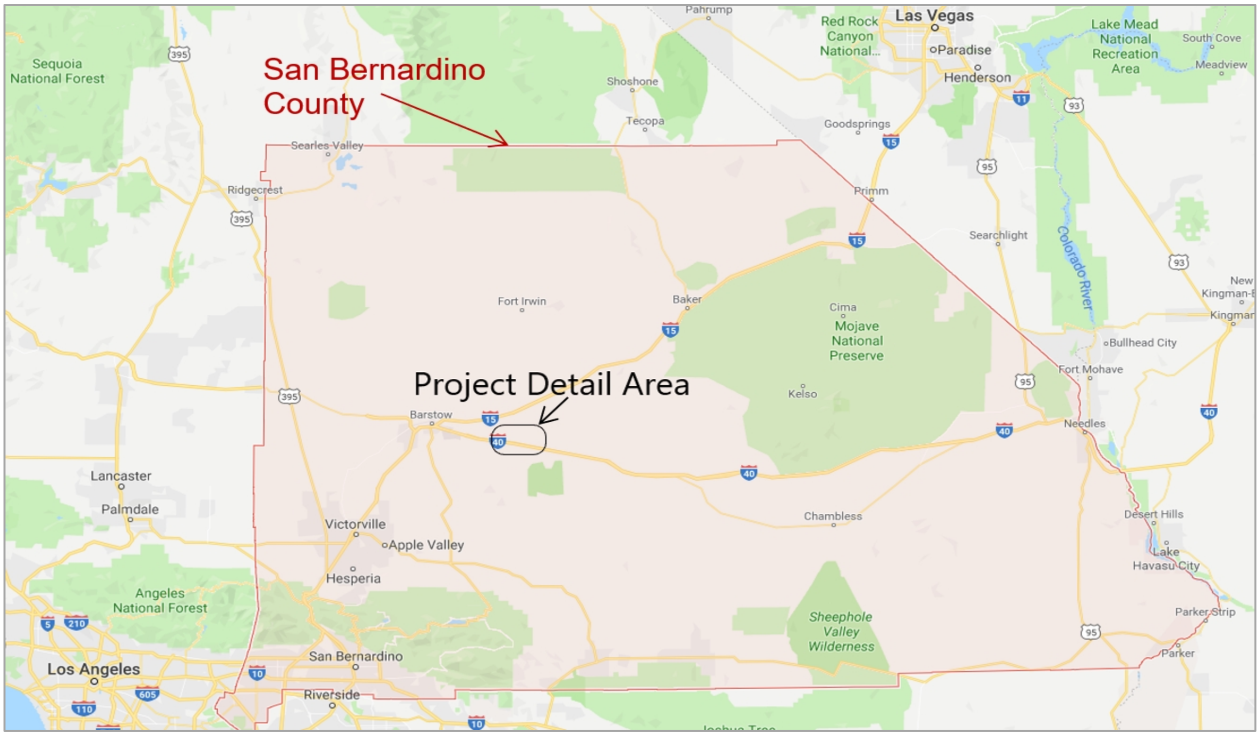
CASE STUDY: SBC DEPARTMENT OF PUBLIC WORKS

Using Chip Seals on County Roads

Background

Located northeast of Los Angeles, SBC is the largest county in California at 20,105 sq mi (figure 10). SBC covers approximately 12 percent of California's land mass and has diverse features ranging from urban communities on its western border to rural, open desert on its eastern border. Aggregate supply is scarce in less populated areas. For example, conventional chip seals often require hauling materials over 100 mi to project destinations.[7]

[7]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.



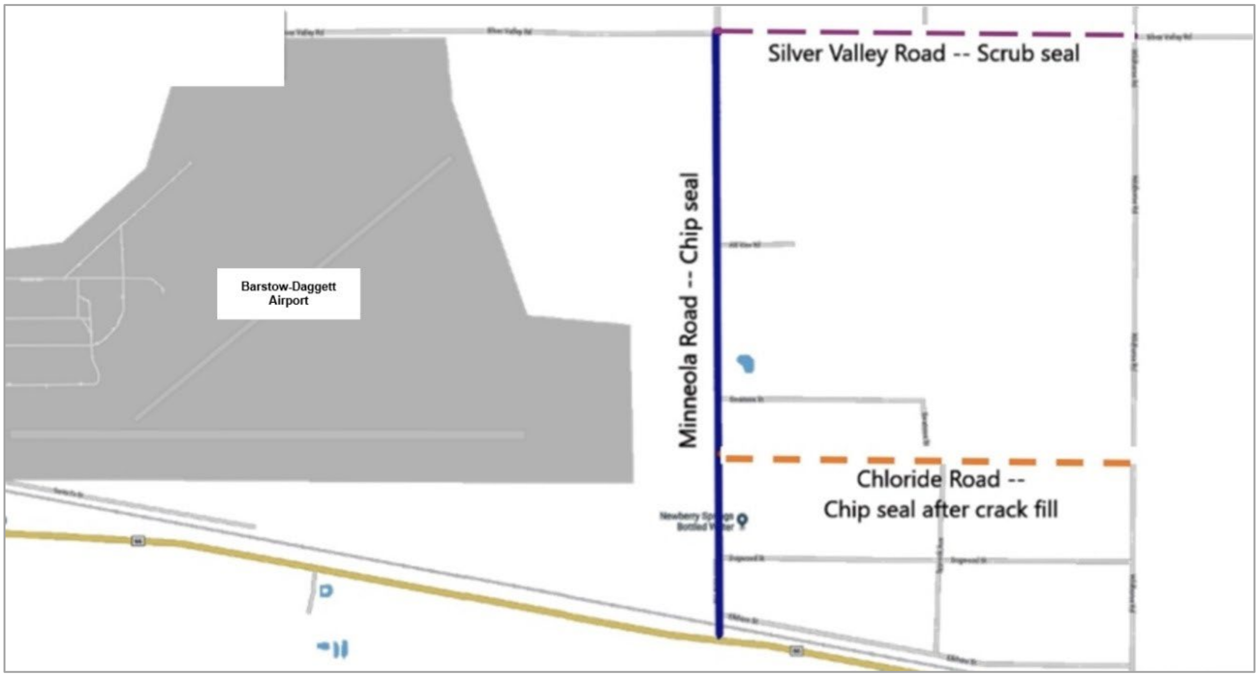
Map data © 2020 Google with overlay of an oval over the Project Detail Area and label for San Bernardino County outline.

Figure 10. Map. SBC is located between Los Angeles, CA, and Las Vegas, NV.

SBC used RAP in chip seals since 2014. A public works crew manager identified example pavements that were chip sealed in 2016 and examples from the 2018 paving season.[8] The approximate project locations are identified in figure 10 as the Project Detail Area located east of Barstow, CA. Projects from 2018 located east of Barstow–Daggett Airport are shown in figure 11. SBC applies chip seals with a specialized crew and contracts for emulsion and aggregate delivery to the project site. The RAGG can be delivered to the crew during construction or a few days prior to construction depending on their expected production rate. If the crew is only placing short runs in a neighborhood, contractors are required to deliver materials to the project site and may stockpile it nearby.[9] Table 10 lists the routes and treatments observed by the research team during a site visit on August 7, 2018.

[8]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

[9]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.



Map data © 2018 Google with overlay of lines to show various treatment locations.

Figure 11. Map. SBC roadways with pavement-preservation treatments applied in 2018.

Table 10. SBC roadway and treatment observed.

Roadway	Treatment	Year
Minneola Road	Chip seal	2018
Chloride Road	Chip seal after crack fill	2018
Silver Valley Road	Scrub seal	2018
National Trails Highway from Daggett Yermo Road to Mineola Road	Chip seal	2016
Cedar Avenue	Double chip seal	2016

Starting the Process

SBC began using vendor-supplied RAP as an alternative to virgin aggregate on a trial basis in 2014. Due to the limited supply of virgin aggregate, SBC had difficulty receiving multiple bids on some chip-seal projects. A vendor approached SBC and proposed delivering RAGG to their project sites. Some SBC employees were skeptical that RAP materials could provide a high-quality surface equivalent to virgin aggregates. After learning LAC used RAP materials for several years and reported satisfactory results, SBC officials visited LAC project sites and saw that RAP materials performed adequately and were worth trying on their network. As SBC applied RAP treatments to multiple trial sections, the SBC Department of Public Works staff carefully observed the treatments' performance.

The performance of the RAP trial sections was on par with that expected from virgin aggregate. The SBC Department of Public Works staff who were skeptical about RAP materials were encouraged to experiment more with new processes.[10] After success with the trial sections, SBC began accepting alternative bids for either virgin aggregate or RAGG for advertised projects. In most cases where RAP was permitted as an alternative, it was the low bid. However, trucking and haul costs contributed significantly in determining which aggregate was provided most economically. In some cases, virgin aggregate was delivered to a project site more economically than RAGG. However, choosing roadways in the proper condition was most important to chip seals performing as expected regardless of which aggregate was used.

Treatment Selection

Based on network-level triggers, SBC's Pavement Management Division recommends roadways for preventive maintenance and requests a project-level evaluation to confirm the right treatment. The project-level evaluation also lists maintenance that should be performed prior to treatment application. The project-level evaluation is then provided to a local maintenance crew that prepares the site. Site preparation consists of patching potholes, grader-placed leveling courses, filling cracks, and grading shoulders and ditches.

Ideally, SBC waits 6 mo between filling cracks and treatment application so crack-filling material has adequate time to cure. High work demands on maintenance crews often delay such preliminary work, preventing the crack-filling material from adequately curing. At times, pretreatment occurs only 1 mo ahead of chip seal application, which can cause the sealant to bleed through the chip seal.

As a treatment alternative, SBC used rejuvenating scrub seals on pavements with higher extents of block cracking, weathering, and raveling. For example, Silver Valley Road had extensive medium-severity block cracking. Because a scrub seal was proposed, this roadway section was not pretreated (i.e., there was no crack filling). The rejuvenating emulsion filled the cracks as the scrub-seal broom passed (figure 12). The emulsion was then covered with 0.3125-inch RAP chips, and a fog seal was applied a few days after.

[10]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

Source: FHWA.

Figure 12. Photo. Scrub and fog seals applied on Silver Valley Road.

Bid Specifications

Chip seal materials were bid using the specifications in Caltrans Section 37, Seal Coats, and the SSPWC, as shown in table 11 (BNI 2018). RAGG must meet a gradation and a cleanliness specification.[11] Virgin aggregate must meet the required gradation and a minimum sand equivalent of 80, and RAGG must meet the same minimum sand equivalent of 80 (BNI 2015).SBC provided researchers with purchase orders containing the following specifications for chip deliveries:

> Approximately 2,000 tons of chip seal screening, medium-fine $^{5}/_{16}$ inch × No. 8 virgin and RAP accepted. Delivered to job per schedule. Trucks must have a chip bar, working backup alarm, and CB-radio to communicate with chip spreader operator. (SBCDPW 2018)

[11]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

Table 11. Medium-fine chip grading requirements from the SSPWC.

Sieve Size	Medium Fine 5/16 Inch × No. 8 (8.00 × 2.36 mm) Percentage Passing Sieve
⅜ inch (9.50 mm)	100
No. 4 (4.75 mm)	0–50
No. 8 (2.36 mm)	0–15
No. 16 (1.18 mm)	0–5
No. 30 (600 µm)	0–3
No. 200 (75 µm)	0–2

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.

Chip Seal Application

SBC uses the same application rates for RAGG and virgin aggregate.[12] SBC's most common chip seal specification uses 0.32 gal/sq yd of asphalt emulsion with a 0.3125-inch aggregate placed at 19 to 20 lb/sq yd for cover. The most common asphalt emulsion SBC uses is a polymer-modified cationic rapid set emulsion. A cationic quickset emulsion (CQS-1h) fog seal is typically applied at 0.1 gal/sq yd on top of the chip seal to minimize chip loss and to uniformly color the pavement surface black.

The specialized chip seal crew treats approximately 200 centerline-miles annually during paving season. The crew adapted to using RAGG with no adverse constructability issues. Some crewmembers were skeptical during the trial period but have come to accept RAP as a suitable alternative to virgin chips.[13]

Quality Monitoring

SBC uses a third-party consultant to test the delivered materials, verify they meet all bid specifications, and serve as an inspector for the specialized chip seal crew. The consultant runs compatibility tests to ensure the source materials will combine adequately with available asphalt emulsion materials. The consultant is on site with the specialized chip seal crew during the daytime as materials are placed; runs daily gradation tests; and documents crew actions, material properties, and application rates. The consultant prepares a report at the end of each project and delivers it to SBC. The report provides a QA/QC record for the SBC Department of Public Works to maintain consistency and accountability among the specialized chip seal crew.

Observations after Treatment

SBC reported lower chip loss using RAGG compared to virgin aggregate (figure 13). The asphalt film on the RAP chips may enhance bonding, and the fine particles on the chips may act as a choke stone, increasing texture density and reducing chip loss.

[12]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

[13]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

Source: FHWA.

Figure 13. Photo. Minimal chip loss on Mineola Road.

As noted previously, the timing between crack sealing and applying chip seals is important. A chip seal was applied after extensive crack sealing on Chloride Road (figure 14), and the crack-filling material was observed bleeding through the chip seal surface. Crack filling was completed a few weeks prior to applying the chip seal and there was only limited curing. In low areas of Chloride Road, where stormwater often overtops the roadway, there was moderate to severe transverse cracking with "cupping" at the edges (figure 15). In these instances, the pavement protruded upward to form vertical ridges along the crack edge. In contrast, adjacent areas were depressed.

Source: FHWA.

Figure 14. Photo. RAP chip seal applied over extensive crack filling.

Source: FHWA.

Figure 15. Photo. "Cupping" at the crack edge underneath a RAP chip seal.

SBC encountered other challenges with RAP treatments. Cedar Avenue, a heavy arterial roadway, was treated using a double-layer RAP chip seal. In advance of a signalized intersection, there was minor rutting with significant wheelpath bleeding (figure 16). SBC managers believe the asphalt content in the RAGG may contribute bleeding but would not be as severe if virgin chips were used in at least one layer.[14] SBC managers also believe the binder shot rate needs reducing if any additional treatments are applied.

[14]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. Interview, August 7. Daggett, CA.

Source: FHWA.

Figure 16. Photo. Rutting and wheelpath bleeding in advance of an intersection on Cedar Avenue.

RAP scrub seals generally have a smooth surface (figure 17). The 0.3125-inch maximum aggregate size fits together more tightly than larger aggregate, and the fines and small particles that adhere to RAP give it a smoother surface than virgin aggregate.

As expected with other chip seals, transverse cracks reflected through the surface and reestablished themselves. At the section applied in 2016, cracks reflected at the previous transverse crack and other distress locations (figure 18). At the sections applied in 2018, there was cracking; however, there was not enough movement for fresh crack sides.

Source: FHWA.

Figure 17. Photo. Smooth surface of a RAP scrub and fog seal.

Source: FHWA.

Figure 18. Photo. Cracks reflecting through a RAP scrub seal on National Trails Highway.

Cost Implications of Using RAP in Surface Treatments

Table 12 is a bid comparison provided by SBC for two projects that received multiple bids where RAP chips were bid as a substitute for virgin chips. RAP chips were 20- to 27-percent less expensive than virgin chips.

Table 12. Bid price comparison of RAP and virgin aggregate for chip seals.

Bid Number	Delivery Location	Approximate Haul Distance (Mile)	RAP Price (U.S. Dollars)	Virgin Aggregate Price (U.S. Dollars)	Savings (Percent)
5422	Daggett, CA	92	47.20	59.40	20
5509	Wrightwood, CA	40	31.25	42.95	27

Delivery costs vary depending on where the aggregate quarries and RAP processing centers are located in relation to stockpiles or project sites.

Conclusions

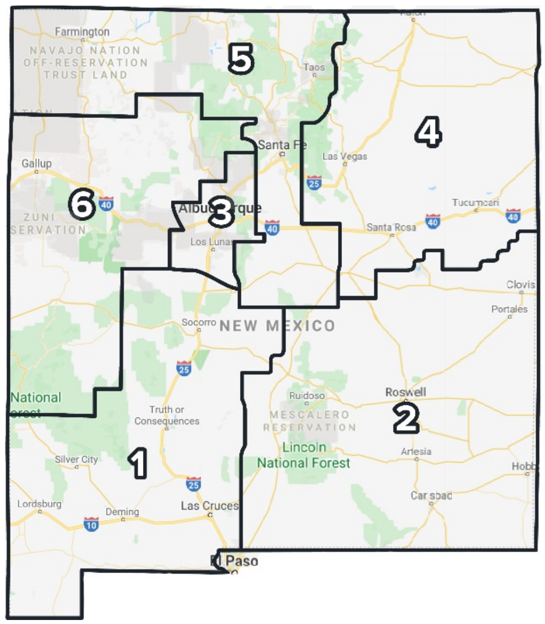
SBC saved money on chip seal projects by allowing contractors to bid RAGG as a substitute for virgin materials with some projects seeing cost savings more than 25 percent. The performance characteristics for chip seal were similar whether RAGG or virgin aggregate was used. The specialized chip seal crew learned to place RAGG chip seals with no modifications to their typical process, saving SBC additional money. RAGG chips have less tendency to be swept away than virgin aggregate, and RAGG chip seals have a smoother surface than those with virgin aggregate. Multilayer chip seals using RAGG tended to bleed more than those with virgin chips, making SBC hesitant to use RAP in more than one layer. Understanding that across-county material deliveries are not always feasible, RAP provided SBC with a viable substitute for virgin materials for competitive bidding and project success.

CASE STUDY: NMDOT

Chip Seals on State Routes in District 6

Background

NMDOT used RAP in their chip seals. The driving force behind this was the need for aggregate meeting surface use specifications, which was in short supply in some districts (figure 19). NMDOT accumulated abundant RAP tonnage from resurfacing projects where cold planing removed the surface layer of existing pavement. In approximately 80 percent of the projects using cold planing, the millings were stockpiled at State right-of-way (ROW) locations convenient to NMDOT.[15] District 6 has been a leader in RAP chip seals since 2014 when three sections were applied for a research project with the University of New Mexico (UNM).



© 2020 Google, INEGI with overlay of lines/numbers to show NMDOT districts.

Figure 19. Map. NMDOT district map.

How to Best Use RAP

With thousands of tons of RAP stockpiled across the State (figure 20), NMDOT contracted with UNM to investigate how best to use the resource. The district 6 construction manager said, “We own the resource … we need to be using it. Financial gains and environmental aspects are good selling points.”[16] Tarefder and Ahmad (2017) concluded using RAP can help NMDOT achieve their maintenance goals and reduce the need for virgin aggregate. Chip seals with RAGG had similar performance characteristics to those of virgin aggregate. Tarefder and Ahmad (2017) recommended standard processes for applying chip seals across New Mexico. In addition to

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[15]Employees of NMDOT. 2018. Interview by Gregory Duncan. May 16. Albuquerque, NM.
[16]Employees of NMDOT district 6. 2018. Interview by Gregory Duncan. May 17. Grants, NM.

using RAP in chip seals, NMDOT mixed emulsified asphalt with RAP in a pugmill at a cold central plant and applied a 3-inch lift with an asphalt paving machine.

Source: FHWA.

Figure 20. Photo. RAP stored at a ROW on NM 124 prior to crushing and fractionating.

Cost Implications of Using RAP in Surface Treatments

RAGG must be fractionated before being used for chip seals. A crusher reduces oversized material to the desired size and the material passes a series of screens that separate the correctly sized material from finer particles. Finer materials pass through the screen and are stockpiled adjacent to the original pile, while correctly sized material is trucked to a staging location. NMDOT contracts this processing to vendors who fractionate RAGG and haul them to various locations where chip seals will be applied the following year. NMDOT has a specialized chip seal crew who travels district 6 and applies all the seals.[17] Table 13 lists contract bid quantities and prices for fractionation and delivery to project sites across district 6 based on the district-wide contracts awarded in 2015 and 2016. The 2015 contract required virgin aggregate, while the 2016 contract permits the agency's RAP piles to be used as a source. Compared to the costs per ton of RAGG and virgin aggregate, processing RAGG and delivering it to district-wide stockpiles saved NMDOT over 40 percent.

[17]Employees of NMDOT district 6. 2018. Interview by Gregory Duncan. May 17. Grants, NM.

Table 13. Price comparison for RAP and virgin chips.

Contract	Year	Quantity (Tons)	Bid Price (U.S. Dollars/Ton)	Total Price (U.S. Dollars/Ton)
6100299-RAP chips	2015	25,431	20.96	23.50
6100289R-Virgin chips	2016	26,967	38.30	40.21

Note: RAP chips quantity is estimated 100 lb/cu ft for dry rodded unit weight to convert bid cu yd to tons. Traffic control and mobilization items were included for total cost.

High-quality aggregate suitable for pavement-preservation treatments is usually imported from outside district 6. Although the haul distance can be more than 75 mi, significantly impacting aggregate supply cost, other factors make using RAP an economical option for pavement-preservation treatments. Milled materials are stored at NMDOT ROWs within district 6, so haul distances to project staging areas are often shorter than from aggregate quarries. Because fractionating quarried materials is a component of aggregate production, fractionating RAGG can be a less expensive process than mining, crushing, and screening virgin aggregate. Costs for moving a fractionation unit are significant, but if several thousand tons of materials are processed per relocation, the costs are justifiable.

Most resurfacing projects performed for NMDOT, where cold planing is a component, used NMDOT's apportioned Federal funds. When millings are stored at NMDOT ROWs, they have a salvage value and their use is tracked and reported to the Federal Highway Administration's New Mexico Division. NMDOT is permitted to use the millings for maintenance purposes, but 70 percent must be used on Federal-aid-eligible roadways.[18] Quantities used from the stockpiles are tracked using the NMDOT maintenance management system, and a report is generated quarterly showing where the millings were used.

Existing Design Practices Used

NMDOT officials indicated that no modifications were required to their process to use RAGG in chip seals.[19] NMDOT uses crew supervisor field experience to design chip seal binder and aggregate placement rates by placing a test strip to calibrate binder application and chip spread rates. Although there is a slight reduction in binder application rate for RAP chip seals, the rate differences depend on the preapplication pavement condition. Pavements with more extensive oxidation or weathering require a higher binder application rate.

Similar fractionation and delivery processes were used for both RAGG and virgin aggregate. Chip gradation was specified in the contract, and inspectors performed washed gradations on delivered materials to verify the size distribution matched the specification. The specifications listed for each material are shown in table 14. Both specifications required the contractor to correct the gradation if the materials were outside specification parameters.

[18]Employees of NMDOT district 6. 2018. Interview by Gregory Duncan. May 17. Grants, NM.
[19]Employees of NMDOT. 2018. Interview by Gregory Duncan. May 16. Albuquerque, NM.

Table 14. NMDOT chip seal gradation specifications.

Sieve Size	RAP Chips (Percent Passing)	Virgin Chips (Percent Passing)
¾ inch	100	100
½ inch	95–100	95–100
⅜ inch	0–70	N/A
No. 4	0–6	0–6
No. 10	0–2	0–4
No. 200	N/A	0–2

N/A = not applicable.

Performance Characteristics

Surface friction values were monitored by the NMDOT Materials Division and are shown in table 15. Montoya (2018) found sections with RAP chip seals had friction values similar to those with virgin aggregate.

Table 15. Friction measurement on RAP chip seals.

New Mexico Roadway	Friction Number Average, S_{n40}	
	RAP	Virgin
NM 124 in Cibola County	43.6	45.6
NM 126 in Sandoval County	42.5	47.4
NM 197 in Sandoval County	42.2	41.0

S_{n40} = skid number at 40 mph.

Tarefder and Ahmad (2017) found comparable surface texture and bond between chip seals with RAGG and those with virgin aggregate. Figure 21 shows the construction of a RAP chip seal, while figure 22 through figure 25 demonstrate the surface variance in typical RAP chip seals. In figure 22, the surface of the RAP chip seal on NM 124 appears uniform without significant chip loss or wheelpath bleeding.

Figure 21. Photo. Chip spreader applying RAP chips on NM 126 (Tarefder and Ahmad 2017).

Source: FHWA.

Figure 22. Photo. RAP chip seal applied on NM 124.

Figure 23 shows bleeding in the RAP chip seal applied on NM 126. Bleeding in chip seals is a common deficiency from applying too much binder, chip loss after placement, and/or flat or elongated particles orienting under traffic loading. NMDOT officials reported that bleeding is similar in both RAP chip seals and those with virgin aggregate and is caused by over applying binder material.[20]

[20]Employees of NMDOT district 6. 2018. Interview by Gregory Duncan. May 17. Grants, NM.

Source: FHWA.

Figure 23. Photo. RAP chip seal on NM 126 with flushed wheelpaths.

There are fine conglomerates and discrete RAP particles with intermittent asphalt coating on the surface of NM 197 (figure 24). The coarse particles lost their asphalt coating at the surface interface, which was expected due vehicle traffic and weathering. The fine conglomerates retained the asphalt matrix around the particles and may provide prolonged resistance to weathering.

Source: FHWA.

Figure 24. Photo. RAP chip seal on NM 197 with asphalt coating loss.

Considerable fine aggregate is visibly embedded between the coarse particles on NM 126 (figure 25). A 1-inch-square coated conglomerate is visible in the center-right of the photo, but the RAP asphalt coating was stripped away from the remainder of the RAGG. The surface texture has the appearance of a virgin chip seal had a fine choke stone applied to improve aggregate retention. After 4 yr in service, there was significant weathering and the RAP asphalt coating was only slightly visible, except in conglomerates.

Source: FHWA.

Figure 25. Photo. RAP chip seal on NM 126 with significant weathering.

Performance of RAP Surface Treatments

Through the 4 yr the surface treatments have been in place in district 6, treatments using RAGG performed as well as those using virgin aggregate. Treatments using RAGG retain their black color longer than treatments using virgin aggregate, improving the contrast to pavement markings.[21] The coating of asphalt on the RAP may provide prolonged resistance to oxidation, an improved bond, and subsequently fewer chips wasted. The lane where a treatment using RAGG was applied was a darker shade than the lane where a treatment using virgin aggregate was applied on NM 197 (figure 26). Both lanes were treated within a few days of one another as part of the same project.

[21]Employees of NMDOT district 6. 2018. Interview by Gregory Duncan. May 17. Grants, NM.

Source: FHWA.

Figure 26. Photo. Color difference between a surface treatment using RAGG and another using virgin aggregate on NM 197.

Needs and Next Steps

The fine aggregate passing through the screens during RAP fractionation is stockpiled similarly to coarse RAGG and accounts for as much as 50 percent of the original pile (figure 27). NMDOT considered using the fine portion for other pavement-preservation purposes, but the only large-scale use was in cold central-plant recycling. Small-scale uses included stabilized-shoulder maintenance and pipe-bedding material. District officials were open to trying a microsurface using RAP, and because the gradation resembles International Slurry Seal Association (ISSA) Type I or II material, a microsurface would be feasible on NMDOT roadways.[22]

[22]Employees of NMDOT district 6. Interview by Gregory Duncan. May 17. Grants, NM.

Source: FHWA.

Figure 27. Photo. RAP stockpile containing intermediate and fine sized particles after removing chips.

Conclusions

NMDOT successfully used applied chip seals using RAGG in pavement-preservation projects. NMDOT developed contracts to fractionate NMDOT-owned RAP stockpiles and implemented acceptance processes to verify the chips met NMDOT contract specifications. Using RAGG from stockpiles instead of having virgin chips delivered to project sites, NMDOT saved approximately 40 percent. Several NMDOT officials said chip seals using RAGG performed equally to those using virgin chips through the 4 yr the treatments were observed. NMDOT also provided test reports confirming the surface friction characteristics are similar between RAGG and virgin chips.

While using RAGG chips reduced costs and increased sustainability for NMDOT, their availability is finite. To make the most of their resource, MNDOT uses the fine materials produced by fractionating RAP for other maintenance purposes and pavement-preservation treatments.

CASE STUDY: PTL

Chip Seal, Slurry Seal, and Microsurface Treatment Design

Background

This PTL was a production and development asphalt laboratory providing mix designs for chip seals, slurry seals, and microsurfaces. The PTL produced several mix designs using RAP as the primary aggregate and provided mix design documentation for researchers to evaluate. According to the PTL manager, virgin aggregate can be replaced with 100 percent RAGG if the RAP is fractionated and graded to separate the coarse particles from the fine portion. The coarse particles are used in chip seals, while the fine portion is used in slurry seals or microsurfaces.[23] The RAP stockpile must not be contaminated with metals, fibers, or soils and the source aggregate properties must meet other requirements in agency specifications for the type of pavement-preservation treatment.

This PTL used American Association of State Highway and Transportation Officials (AASHTO), ISSA, and ASTM test methods for mix designs. The PTL's design technicians developed mix design procedures allowing for interpolation in establishing mix proportions as long as minimum test-method thresholds are met.

The PTL frequently received RAP samples from customers requesting a determination on their appropriateness for pavement-preservation treatments, including RAP fractionated at the source and stockpiled RAP requiring additional processing. The PTL's RAP processing is similar to that during the project-level fractionating, stockpiling, and construction but on a smaller scale. The samples can have a slight moisture content so the PTL stores the samples in sealed 5-gal containers prior to testing (figure 28 and figure 29). The first step in evaluating RAP samples is determining its gradation as received and after the asphalt is removed or extracted. A furnace is used to remove the asphalt from the aggregate, as specified in AASHTO T 308, *Standard Method of Test for Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method* (AASHTO 2018).

[23]Manager of a PTL. 2018. Interview by Gregory Duncan. April 26.

Source: FHWA.

Figure 28. Photo. Fine RAP materials stored in a 5-gal bucket.

Source: FHWA.

Figure 29. Photo. Fine RAP materials.

RAP Processing Requirements

Stockpiled RAP must be fractionated and graded before it can be used in chip seals, slurry seals, and microsurfaces. RAP, which is composed of whatever mixtures were milled from pavement surfaces, requires a different approach to gradation control than virgin aggregate, which requires only drying before determining the gradation. Fractionating has a limited effect on gradation, and while crushing reduces the aggregate size, it cannot change the basic components of the aggregate. Accordingly, designers of pavement-preservation treatments consider aggregate-grading requirements not as specifications but as guidelines. In coarse fractionated material, fine particles adhere to larger particles, and even finer particles adhere to those fine particles. Researchers questioned whether a grading control should be placed on the RAP material for treatment design; if so, should it be on the gradation of the RAP as it exists in the stockpile or after removing the asphalt? PTL reports both gradations, which allows specifying agencies and contractors to use the information for QC/QA decisions.

Specifications

Using RAP in pavement-preservation treatments was a new practice for this PTL. According to the PTL manager, while some agencies developed specifications for pavement-preservation treatments using RAP, most relied on concepts from contractors proposing RAP alternatives to virgin aggregate. When designing and applying pavement-preservation treatments using RAP, agencies used their typical specifications with RAP controls added.

Mix Design Testing Modifications

The PTL used standard ASTM and ISSA tests to characterize RAP materials as received (i.e., coated with asphalt and slightly moist) and blended with an asphalt emulsion for the proposed pavement-preservation treatment. Like gradation, requirements for total asphalt content in RAP blends viewed as guidelines rather than specifications. Emulsion content and application rates were established from standard performance-related design criteria and were largely based on the amount of asphalt emulsion required to meet the design parameters of a proposed pavement-preservation treatment. The total asphalt content of the mixture includes the asphalt in the RAP and the emulsion content added.

Chip Seals

Although compatibility testing was still required, there were no differences in required binder properties for chip seals using RAGG and those using virgin aggregate. The PTL designed chip seals according to ASTM D5360, *Standard Practice for Design and Construction of Bituminous Surface Treatments* (ASTM 2015a). In addition, the PTL evaluated the bond between bituminous materials and chips designated for a project using ASTM D7000, the outcome of which is a calculated chip loss rate for the proposed emulsion binder and chip (figure 30), *Standard Test Method for Sweep Test of Bituminous Emulsion Surface Treatment Samples* (ASTM 2019a). The Sweep Test outcome is a calculated chip loss rate for the proposed emulsion binder and chip. It is a torture test that provides confidence that the bond developed between the proposed binder and aggregate particles is acceptable. The lab manager stated that RAGG and virgin aggregate had comparable results.

Source: FHWA.

Figure 30. Photo. Testing the bond between asphalt binder and chips.

Slurry Seals and Microsurfaces

During the slurry seal and microsurface design process, asphalt emulsion percentages were varied and mixed (figure 31) and the RAGG–emulsion combinations were compared using ASTM D3910, *Standard Practices for Design, Testing, and Construction of Slurry Seal*, and ISSA TB-100, *Laboratory Test Method for Wet Track Abrasion of Slurry Surfacing Systems* (figure 32 and figure 33) (ASTM 2015b; ISSA 2018a). Blends were also tested using ISSA TB-109, *Test Method for Measurement of Excess Asphalt In Bituminous Mixtures by Use of a Loaded Wheel Tester and Sand Adhesion* (figure 34) (ISSA 2018b). Based on the PTL's experience, typical RAP treatment mix design produces a slightly lower optimum emulsion content compared to that of virgin aggregate blends. Two factors contributed to RAP's lower optimum emulsion (i.e., required asphalt content): particles were partially coated with asphalt and did not require emulsion to penetrate the voids; and fine conglomerates with less surface area than virgin aggregate. These factors are discussed later in this chapter.

The RAP slurry seal and microsurface mix design reports provided by the PTL indicated both slurry seals and microsurfaces have laboratory design properties that conform to the standard mix design criteria for pavement-preservation treatments. The PTL manager stated that the test properties were similar for pavement-preservation treatments using RAGG and those using virgin aggregate. Table 16 lists key material characteristics from mix designs developed by the PTL.

Table 16. Slurry seal and microsurface mix design characteristics.

Characteristic or Test	Required Value	Roswell, NM, RAP Sample (AG-D1c-1487) Microsurface	Roswell, NM, RAP Sample (AGD1d-507) Slurry Seal	Fontana, CA, RAP Sample (AGA2e-1119) Slurry Seal	Fontana, CA, RAP Sample (AGD1e-989) Slurry Seal
WTAT 1-hr soak (g/sq ft) ISSA TB-100 (ISSA 2018a)	<50	35.00	19.00	9.00	12.00
WTAT 6-d soak (g/sq ft) ISSA TB-100 (ISSA 2018a)	<75	60.00	N/A	N/A	N/A
Monolayer Loaded Wheel Test (g/sq ft) ISSA TB-109 (ISSA 2018b)	<50	14.00	21.00	22.00	13.00
Multilayer Loaded Wheel Test, percent vertical compaction ISSA TB-147 (ISSA 2008)	<10	8.00	N/A	N/A	N/A
Multilayer Loaded Wheel Test, percent lateral displacement ISSA TB-147 (ISSA 2008)	<10	0.73	N/A	N/A	N/A
Optimum emulsion content, percent by weight of aggregate ISSA A105 (ISSA 2010)	—	11.50	12.00	12.50	12.00
AC from emulsion, percent by weight of aggregate	—	7.42	7.84	8.14	7.78
AC from RAP, percent by weight of aggregate	—	7.06	8.80	6.72	6.13
Total AC, percent by weight of aggregate	—	14.48	16.64	14.86	13.91

—No data.
N/A = not applicable.

Source: FHWA.

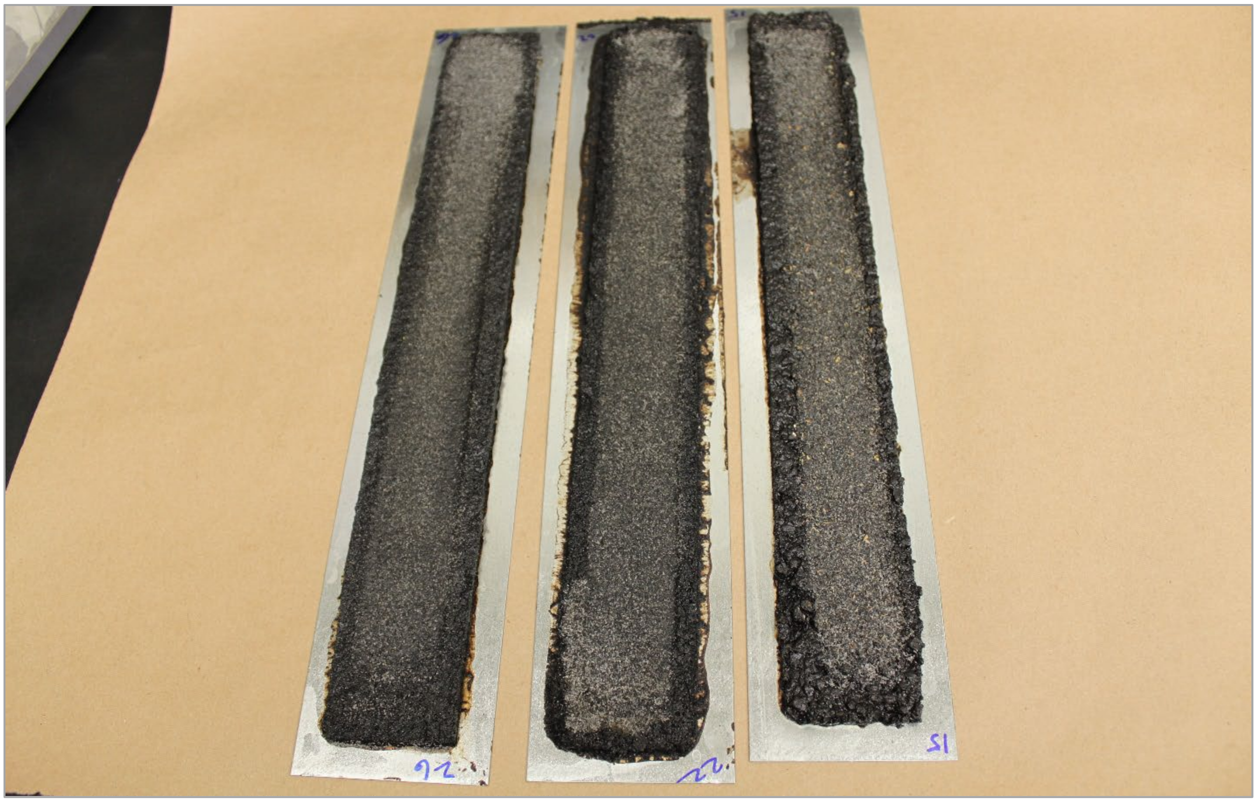
Figure 31. Photo. RAP hand mixed with a trial emulsion.

Source: FHWA.

Figure 32. Photo. RAP slurry seal tested using the WTAT.

Source: FHWA.

Figure 33. Photo. Slurry seal samples tested using the WTAT to determine the potential for stone loss.



Source: FHWA.

Figure 34. Photo. RAP microsurface trial blends tested using the Loaded Wheel Test.

Gradation

Slurry seals and microsurfaces are commonly specified according to ISSA standard types shown in table 17, depending on the treatment use and the condition of the pavement receiving the treatment.

Table 17. ISSA gradation requirements for aggregates in slurry seals and microsurfaces.

Sieve Size	Type I Percent Passing	Type II Percent Passing	Type III Percent Passing	Stockpile Tolerance from the Mix Design (Percent)
⅜ inch (9.50 mm)	100	100	100	—
No. 4 (4.75 mm)	100	90–100	70–90	±5
No. 8 (2.36 mm)	90–100	65–90	45–70	±5
No. 16 (1.18 mm)	65–90	45–70	28–50	±5
No. 30 (600 µm)	40–65	30–50	19–34	±5
No. 50 (300 µm)	25–42	18–30	12–25	±4
No. 100 (150 µm)	15–30	10–21	7–18	±3
No. 200 (75 µm)	10–20	5–15	5–15	±2

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.
—No data.

The required tests yield a washed gradation of virgin aggregate used in a mixture design. A washed gradation of as-received RAGG leaves conglomerated particles, so extraction or ignition tests are required to remove the asphalt and allow the gradation measurements as intended by AASHTO T 27, *Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates*, and AASHTO T 11, *Standard Method of Test for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing* (AASHTO 2005; 2014). Table 18 and table 19 illustrate the differences in gradation between as-received washed RAP samples and their extracted counterparts. Percent passing differences between the washed and extracted samples were greater than 20 percent in some cases, indicating significant adhesion and conglomeration of fine aggregates. Extraction releases the adhesive bonds causing conglomeration and the gradation becomes finer. The four samples evaluated fall between a Type II and III material. Table 18 and table 19 indicate where the percent passing values do not conform to a standard ISSA gradation type.

Table 18. Washed and extracted gradation results for Roswell, NM, RAP samples.

Sieve Size	Roswell, NM, RAP Sample (AG-D1c-1487)		Roswell, NM, RAP Sample (AGD1d-507)	
	Washed Sample (Percent Passing)	Extracted Sample (Percent Passing)	Washed Sample (Percent Passing)	Extracted Sample (Percent Passing)
⅜ inch (9.50 mm)	100	100	100	100
No. 4 (4.75 mm)	89*	94	82	88
No. 8 (2.36 mm)	60*	72	49	62
No. 16 (1.18 mm)	40*	59	29	45
No. 30 (600 µm)	27*	49	17*	34
No. 50 (300 µm)	17*	40	9*	25
No. 100 (150 µm)	10	27*	4.9*	18
No. 200 (75 µm)	5.8	14.9	2.8*	13.8
Asphalt content	—	7.06	—	8.80
Notes	Coarse Type II	Fine Type II	Coarse Type III	Fine Type III

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.
*Passing values do not conform to a standard ISSA gradation type.
—No data.

Table 19. Washed and extracted gradation results for Fontana, CA, RAP sources.

Sieve Size	Fontana, CA, RAP Sample (AGA2e-1119)		Fontana, CA, RAP Sample (AGD1e-989)	
	Washed Sample (Percent Passing)	Extracted Sample (Percent Passing)	Washed Sample (Percent Passing)	Extracted Sample (Percent Passing)
⅜ inch (9.50 mm)	100	100	100	100
No. 4 (4.75 mm)	96*	100	97*	100
No. 8 (2.36 mm)	64	86	52	76
No. 16 (1.18 mm)	39	66	28	56
No. 30 (600 µm)	23	46	14*	41
No. 50 (300 µm)	12	29	7*	28
No. 100 (150 µm)	7	19	4.3*	19
No. 200 (75 µm)	5.7	13.5	3.2*	12.3
Asphalt content	—	6.72	—	6.13
Notes	Type III except No. 4 screen	Type II	Like Type III but fine on No. 4 screen and coarse on No. 30 to No. 200	Type II

1 mm = 0.039 inches; 1 µm = 3.937E−8 inches.
*Passing values do not conform to a standard ISSA gradation type.
—No data.

Less Binder Required

Less binder is required for slurry seals and microsurfaces when RAP is used. As noted previously in this chapter, two factors contributed to RAP's lower optimum emulsion (i.e., required asphalt content): particles were partially coated with asphalt and did not require emulsion to penetrate the voids; and fine conglomerates with less surface area than virgin aggregate.

The total emulsion content required for a slurry seal or microsurface can be broken into two portions: the first coats the aggregate and the second fills the voids between the aggregate and provides workability for the treatment. The blend gradation and particle shape were major factors in establishing the emulsion percentage needed for coating and workability. Typically, the more material that passes the smallest sieve sizes, the more surface area the blend has and the more emulsion is required to coat all the discreet particles. Additionally, the more angular the particle shape and the rougher the surface texture, the higher the required emulsion content needed for workability. Both factors affected RAP's optimum emulsion requirement because fines adhering to larger particles reduced the total blend surface area but also made the particles more irregularly shaped, somewhat canceling out the effects.

Surface Area Analysis

To evaluate the as-received washed gradation to the extracted gradation, the surface area was calculated using the formula found in *Hot Mix Asphalt Materials, Mixture Design, and Construction, Third Edition* (Brown et al. 2009). Table 20 presents surface area calculations for washed and extracted RAP and a Type II aggregate source. Table 20 also contains the design emulsion content for RAP blends and typical emulsion content for conventional aggregates from Roswell, NM, and Fontana, CA.

Table 20. Optimum emulsion content and blend surface area comparison.

RAP Blend from PTL Mix Designs	Design Emulsion Content (Percent)	Typical Emulsion Content (Percent)	Washed Surface Area (sq ft/lb)	Extracted Surface Area (sq ft/lb)	Example Type II Source
Roswell microsurface	11.5	12.0–13.0	35	72	—
Roswell slurry seal	12.0	12.0–13.0	22	57	—
Fontana slurry seal	12.5	14.0–14.5	32	63	—
Fontana slurry seal 3	12.0	14.0–14.5	22	59	52

Note: Typical emulsion contents based on the anecdotal experience of the PTL manager.
—No data.

From table 20, extracted RAP has double the calculated surface area compared to washed RAP. Further, the example Type II aggregate source has more surface area than the washed RAP but less surface area than the extracted RAP. Despite the magnitude of the difference in surface area between washed and extracted RAP, the significant comparison is between washed RAP and the example Type II aggregate source. While virgin Type II material is finer than washed RAP, it is not as fine as extracted RAP. Assuming the finer particles remain adhered to larger particles through the washing and grading process similarly to how they remain adhered in the mechanical-mixing process, the RAP should require less emulsion to coat the discreet particles.

RAP particle shape and texture cannot be approximated in a convenient manner like the surface area. However, researchers assume the shape irregularities would increase the emulsion needed for workability, but the texture of the particles—because they are already coated with asphalt—would require less emulsion for workability. The overall change in optimum emulsion content is depicted in table 20 as an 8- to 15-percent reduction. The coarser gradation and smoother surface texture have a larger effect on the optimum emulsion content than particle shape.

Cost Implications of Using RAP in Surface Treatments

The 8- to 15-percent reduction in emulsion content can lower material costs for some the preservation treatment. However, slurry and micro surface mix designs are based on the aggregate ton. Because the RAP aggregate also carries 6 to 7 percent asphalt with it, more tons must be delivered to the project during construction. The laboratory staff also noted the potential for a slight difference in emulsion formulation used for RAP slurry and micro surface. RAGG was less reactive than virgin aggregate and required less chemical retarder added to the blend. If an agency permits bid alternates allowing RAP suppliers to compete directly with virgin aggregate suppliers, RAP suppliers have a competitive advantage with all other factors being equal.

Needs and Next Steps

The PTL manager stated that more research and observation of pavement-preservation treatments using RAP are needed.[24] RAP-asphalt ages to various degrees in service and should not be expected to perform exactly like virgin asphalt or a freshly made asphalt emulsion. The remaining service life of RAP-asphalt is a function of its condition and how much damage was done during its previous service life. The PTL manager suggested materials be graded in some way to correlate how RAP-asphalt condition impacts performance.

Another factor that changes the performance of a pavement-preservation treatment is additional asphalt. Too much asphalt can cause problems in chip seals, slurry seals, and microsurfaces. With chip seal binder requirements unchanged and slurry seal and microsurface emulsion requirements reduced 8 to 15 percent, the total asphalt contained in optimum treatments is higher than typical, especially considering the additional 6 to 7 percent RAP-asphalt included in the mixture. Additional asphalt in pavement-preservation treatments can increase resistance to aging, oxidation, and raveling, or it can reduce stability under loads and increase the risk of bleeding.

Conclusions

The PTL believes pavement-preservation treatments, such as chip seals, slurry seals, and microsurfaces, can be designed to effectively incorporate RAP. However, not all RAP sources should be considered acceptable for pavement-preservation treatments. Improper gradation, contamination by deleterious materials, and a lack of remaining service life in the RAP-asphalt prohibit every stockpile from being as a viable source.[25] Although gradation bands for mix design need redefining because many RAP sources do not meet current ISSA bands for Type I, II, or III, required test parameters for mixture design can be met using RAP. Once a mix design is produced, the RAP materials should be processed immediately to minimize variability and limit the impact of factors like set time and workability.

CASE STUDY: URC

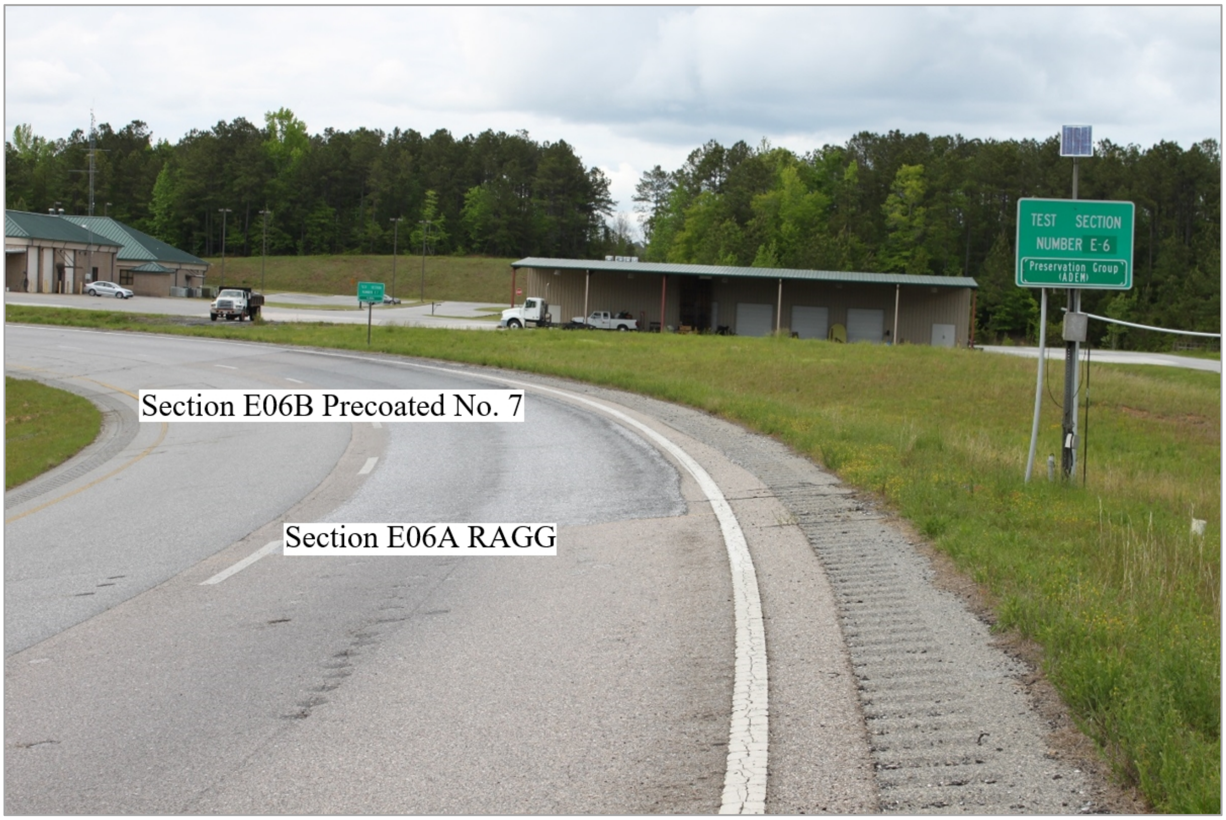
Test Track Sections E06A and E06B

Background

The URC operated a 1.7-mi test track since 2000. Test sections, usually 200 ft long, are constructed according to the research purpose, and the performance of materials, mixture designs, and construction techniques is closely monitored. During their 2015 test track construction cycle, two comparison sections were constructed using a RAGG chip seal and a virgin (i.e., precoated) chip seal. The test section was designated E-6 and was in good condition and could remain in place, making it a strong candidate for a chip seal pavement-preservation treatment. The RAGG section was labeled E06A and the precoated No. 7 aggregate section was labeled E06B (figure 35). The RAP used in the chip seal was from the same DOT-certified stockpile used in other mix designs on the test track. E06A and E06B were approximately 100 ft long, and trafficking included five heavily loaded tractor-trailers providing approximately

[24]Manager of a PTL. 2018. Interview by Gregory Duncan. April 26.
[25]Manager of a PTL. 2018. Interview by Gregory Duncan. April 26.

10 million 18,000-lb equivalent single-axle loads (ESALs) from August 2015 until the experiment concluded in January 2018.



Source: FHWA.

Figure 35. Photo. Test section E-6 at the URC test track.

The RAP and the precoated No. 7 aggregate were placed with an asphalt–rubber tack material made with a 20-percent 16-mesh crumb rubber modifier. The coated materials cohered in the chip spreader and an operator needed to pull the materials with a shovel up the super-elevated slope so they could be dropped uniformly in the binder. Spread rates typical in the northeast United States were used in the test section.

The chip spreader and binder applicator were calibrated on the staging yard to control the material-application rate. Some of the precoated No. 7 aggregate cohered, requiring frequent stockpile reworking to maintain discreet particles. There was no cohesion with the RAGG chips. Table 21 lists the material types for the comparison sections.

Table 21. Chip seal section properties.

Treatment Characteristic	Test Section	
	E06A RAGG Chip Seal	**E06B Precoated No. 7 Chip Seal**
Binder	PG 67-22 with a 20-percent 16-mesh crumb rubber modifier	PG 67-22 with a 20-percent 16-mesh crumb rubber modifier
Shot rate	0.65 gal/sq yd	0.65 gal/sq yd
Aggregate	Coarse fractionated RAGG passing ¾-inch sieve and retained on the No. 4 sieve	No. 7 precoated with 1 percent PG 67-22; 100 percent passing the ¾-inch sieve and no more than 15 percent passing the No. 4 sieve
Source properties	DOT-approved stockpile with unknown properties	DOT-approved granite
Coverage target	28 lb/sq yd*	28 lb/sq yd*

*Construction issues keeping material charged in the chip spreader increased the spread rate in places.
PG = performance grade.

Performance of RAP Surface Treatments

Since constructing E06A and E06B, the URC monitored performance, including mapping cracks, measuring surface texture (i.e., MTD), and periodically testing the skid number value (SN40) of each section.

E06A (i.e., the RAGG test section) performed as well or better than E06B (i.e., the precoated chip test section). Because the pavement-preservation treatments were only in service for approximately 2.5 yr, weathering and raveling were minimal in both. There was minor low-severity cracking in both sections, which likely reflected from the underlying pavement. In the RAGG test section, small aggregate particles were visible, consistent with the concept that fine RAP particles will cling to coarse RAGG particles during fractionation (figure 36). While there was no significant chip loss on the RAGG test section, there was chip loss on the precoated chip test section (figure 37). Both test sections showed wheelpath rutting with bulging on the outside of the wheelpath.

Source: FHWA.

Figure 36. Photo. Test section E06A RAP chip seal texture.

Source: FHWA.

Figure 37. Photo. Test section E06B precoated aggregate No. 7 chip seal texture.

Skid Number

The DOT skid trailer was used to measure SN40 for the sections throughout the loading cycle. The skid value was similar for both test sections during the first year of loading; however, after the first year, the RAGG section had a lower SN40, and by the end of the loading cycle, the difference was between 7 and 11 points for each test (figure 38).

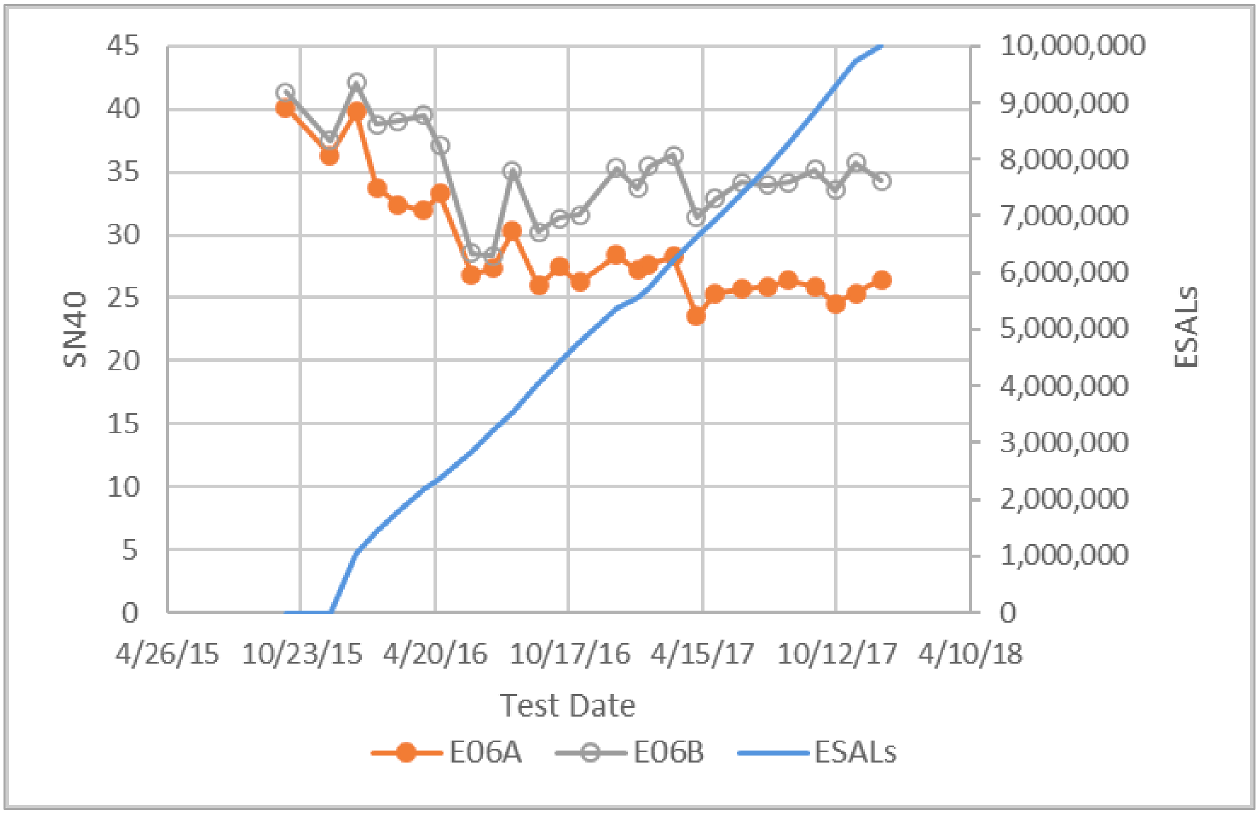


Figure 38. Graph. SN40 comparison for RAGG and precoated chip seals along with applied ESALs.

The source properties for the RAP were not confirmed; however, the coarse aggregate in the RAP appeared to be limestone. Limestone polishing as loads were applied to the surface can account for the lower SN40.

Surface Texture

Surface texture data show the RAGG test section measured slightly higher surface texture than the precoated chip test section (figure 39). However, the 50 ft prior to the test section can influence MTD measurements. According to the URC, the surface texture of both test sections is similar.

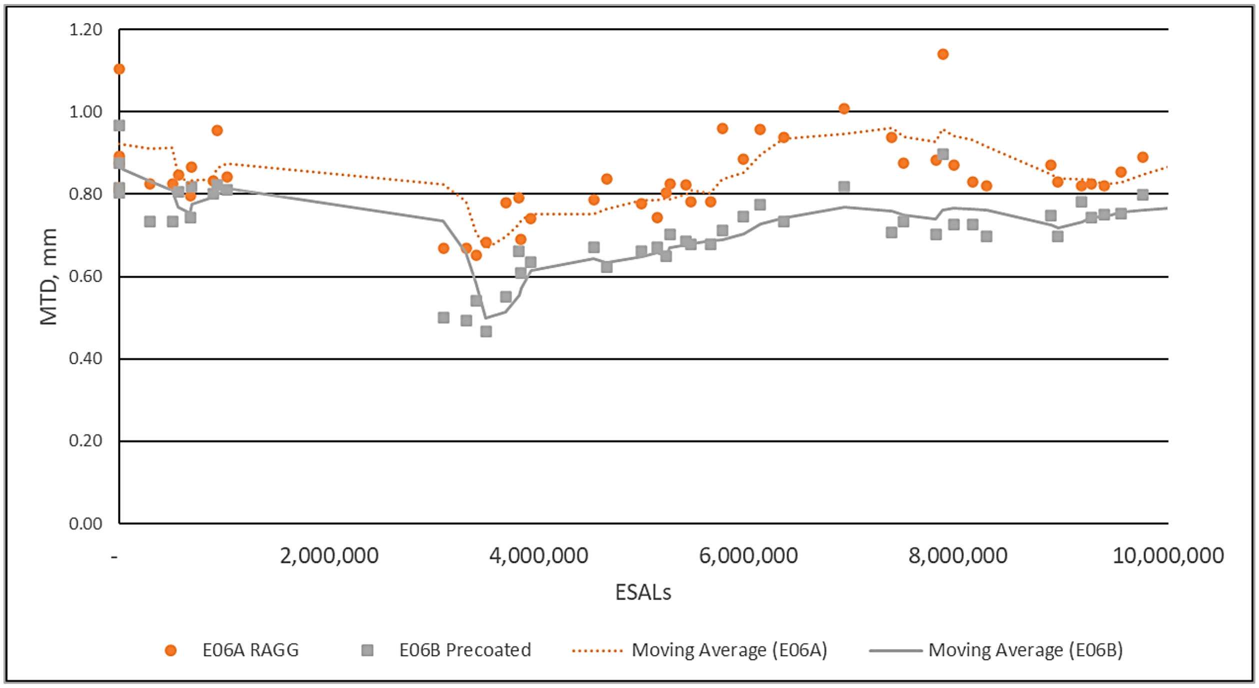


Figure 39. Graph. MTD measured on RAGG and precoated chip seals.

Delamination

During the loading cycle, a short part of test section E06B was removed due to delamination and potholing in the precoated chip seal. Test section E06A showed no signs of delamination after completing the loading cycle.

Needs and Next Steps

The URC has concerns about the potential for cumulative aging of RAP. As cold planing increases based on the pavement-preservation strategies of agencies and the use of OGFCs—which are typically removed rather than paved over—the aged stiffness of RAP will continue increasing. Mixes containing RAP will eventually be cold planed, reclaimed, and reused again. The technology and practice must evolve to incorporate second- and third-generation RAP mixes in the future. Cost savings for RAP chip seals were inconclusive for test section E-6.

The URC manager indicated some of the lessons learned include understanding that multigenerational RAP is likely going to get stiffer.[26] He also noted that this test section was a proof-of-concept application rather than selecting the best pavement-preservation treatment for the condition of the preexisting pavement. The URC's next steps include identifying who owns the RAP stockpiles, the economic advantages of using RAP, and the chemistry of the microreactions so RAP's performance and applicability can be better understood.

[26]Researcher at a URC. 2017. Phone interview by Gregory Duncan. January.

Conclusions

The RAGG chip seal test section applied on the URC's test track performed the same or better than the precoated chip test section in all measures except for SN40. With the presumed source of the RAGG consisting of nonsurface-approved aggregate, there was a higher probability it would polish compared to agency-approved surface aggregate. There was higher chip loss on the precoated chip test section than on the RAGG test section. The URC experimental sections confirmed RAP chip seals can be constructed, and their reaction to loads and weathering early in their service life are similar to precoated chip seals. However, as in-service life expectancy for most chip seals exceeds 2 yr, long-term conclusions cannot be drawn.

CASE STUDY: PPTA

Innovative Practices Lead to Business Success

Background

The PPTA constructed dozens of pavement-preservation projects using RAP as a substitute for virgin aggregate, and the PPTA's president is a leading proponent of using RAP in pavement-preservation treatments. In 2003, two cooperating contractors—the PPTA and a pavement recycling company—investigated ways to increase the use of RAP in chip seals and other pavement-preservation applications.

The pavement recycling company provided asphalt milling and recycling services for many years, typically as a subcontractor on resurfacing or reconstruction projects. Some of the RAP materials were returned to the asphalt producers, but a significant portion was stockpiled in staging and processing yards. Most agencies limit the RAP content permitted in asphalt mixtures, limiting the resale market for RAP and causing RAP stockpiles to grow. At the same time, virgin aggregate was becoming increasingly scarce and expensive. The RAGG met the quality requirements of asphalt production and could be reused for purposes like shoulder stabilization, aggregate base, or pipe embedment material or as a replacement for virgin aggregate in pavement-preservation treatments. Seeking the highest economical use for the materials, the pavement recycling contractor petitioned pavement-preservation contractors to test the theory and treat the growing RAP surplus as a source rather than a waste product. Following a few successful demonstrations, the two companies merged in 2007 to capitalize on the strength of having recycling and pavement-preservation capabilities working together in a partnership. With that confidence and momentum, the partners needed to convince practitioners that using RAP in pavement-preservation treatments did not create an inferior product.[27]

Why Use RAP?

The PPTA found convincing agencies to use RAP required a multifaceted approach. The main considerations were the declining availability of a natural resource (i.e., virgin aggregate), the potential for reduced project costs or increased competition for agency work, and promoting sustainability. As the process gained acceptance, public works agencies were approached and asked to permit RAP as a substitution for virgin aggregate in ongoing contracts. The PPTA

[27]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.

offered to substitute RAP for virgin aggregate as an equally priced pavement-preservation treatment. The PPTA found some agencies receptive to using RAP because of increasing competition and lowering future bid prices, while agencies like LAC were receptive because it fit their overall approach to manage assets more sustainably.

Before agencies were willing to substitute RAP for virgin aggregate, they needed to know if the RAP was dirty. RAGG retains the asphalt coating along with smaller asphalt-coated particles (figure 40). In typical pavement-preservation treatment specifications, dust coatings on the aggregate are detrimental to the performance of the treatment. For instance, a maximum of 1 or 2 percent of material passing the No. 200 sieve is permitted in aggregate used for chip seals; a higher dust content was linked to poor adhesion of the aggregate to the applied binder. The PPTA demonstrated the asphalt coating on RAP chips enhanced the adhesion of the chips to the applied binder in the same manner that precoated chips minimize chip loss after application. The RAP materials were monitored for gradation and cleanliness using QC/QA testing and the process produced materials similar to virgin aggregate.[28]

Source: FHWA.

Figure 40. Photo. RAP chips with a partial coating of asphalt and fine aggregate.

[28]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.

Material Processing

RAP must be fractionated before it can be used in pavement-preservation treatments. Fractionation begins with excavating RAP from a stockpile where it may have been stored for many years. The bulk materials are then crushed and screened to size and the products are separated into chips and fines. Figure 41 shows a bulldozer scarifying a RAP pile in preparation for the fractionation process. Figure 42 shows the layout of a RAP staging yard with a fractionation plant near San Bernardino, CA. The plant consists of a main crushing unit with conveyor belts delivering material from stockpiles and conveyor belts transporting crushed and screened material to multiple stockpiles.

Source: FHWA.

Figure 41. Photo. RAP excavation from a stockpile for processing into chip and fine fractions.

Source: FHWA.

Figure 42. Photo. RAP staging yard with a fractionation plant near San Bernardino, CA.

The PPTA found some fractionated materials clumped together and required rescreening before use. Because there is more asphalt in a pile of RAP fines, they are more likely to clump together than RAP chips.[29] Additional handling and processing increased costs, so maintaining a steady flow of material from the processing yard, to stockpiles, and to project sites was important.

Storing RAP overnight in applicator trucks was not recommended because cohesive bonds formed between some particles. RAP treatments were applied at temperatures between 60 and 105°F, the same minimum and maximum temperature range the PPTA recommended as appropriate for application. If placed at temperatures above 105°F, the RAP became tacky and clogged machine hoppers. If placed at temperatures below 60°F, the surfacing experienced early raveling because the emulsion did not cure sufficiently prior to opening to traffic.[30]

Source and Product Specifications Qualifying RAP Materials for Treatment Use

As the PPTA began applying pavement-preservation treatments using RAP for agencies on a trial basis, their laboratory was evaluating design processes and specifications to determine what changes were necessary to accommodate the different source properties of RAP materials. They

[29]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[30]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.

found that specifications for chip seals using virgin aggregate could be followed with slight changes for RAP materials; more significant changes were required for slurry seals.[31]

ASTM D 2419, *Sand Equivalent Value of Soils and Fine Aggregate*, is often used to limit aggregate source properties, including cleanliness by agency specifications (ASTM 2014). RAGG chips retain a coating of dust and asphalt that increases bonding and retention but decreases the sand equivalent value. This coating often causes RAP to fail cleanliness specifications, but because the dust particles are bound in the asphalt coating, the lower sand equivalent value does not to reduce performance. Thus, it is acceptable to modify cleanliness specifications to allow using RAP in surface treatments.[32]

RAGG processed to Type I (i.e., fine grading) has a relatively high residual asphalt content that causes material handling problems. RAP processed to Type III (i.e., coarse grading) is costly and challenging to create a consistent gradation without blending aggregates after initial fractionation. Further fractionation over a finer screen produces a secondary RAP product even finer than Type I. For most RAP sources, suppliers found polymer-modified Type II RAP the most practical product to produce.[33]

Emulsion for slurry seals or microsurfaces must have a 3-percent polymer modification to enhance initial aggregate retention.[34] Because RAP adds asphalt content into the mixture, there was concern the higher asphalt content would decrease workability and the excess binder would cause bleeding. RAP mix designs use less asphalt emulsion, so a modified emulsion accounting for set timing and grading was used to address aggregate retention. PPTA's laboratory extracted RAP and evaluated the recovered binder. Results from penetration tests on recovered binder typically range from 7 to 30.[35] These values were much lower than typical virgin asphalt binders and indicated significant hardening, which is counterintuitively advantageous in producing good RAP treatments. If penetration values exceed 30, the RAP binder is too soft and the emulsion should be hardened to compensate for the difference. These adjustments must be made by the emulsion producer and require a thorough understanding by both the RAP supplier and the emulsion supplier that the variations in either component affect the resultant materials.[36] This relationship emphasizes the need for frequent QC/QA testing on all material components and open communication between the emulsion supplier, contractor's QC/QA laboratory, and construction crews in the field where changes in material behavior should be acknowledged and reported.

The PPTA's laboratory drafted a RAP slurry seal specification that agencies could incorporate into their contracts. By following the specification, agencies felt assured the trial projects met or exceeded virgin slurry seal test standards and the materials were controllable by the producer.[37] Appendix B contains the RAP slurry seal specification the PPTA developed. Some wrote their

[31]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[32]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[33]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[34]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[35]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[36]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[37]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

own specifications for using RAP materials in pavement-preservation treatments. The specifications used by LAC are outlined in that agency's case study.

The PPTA found some RAP sources unsuitable for use in surface treatments.[38] Factors making RAP unsuitable are soil contamination or the presence of geotextile paving fabrics. Both materials cause adherence issues between the aggregate particles and the asphalt emulsion in chip seals and slurry seals.

Construction Techniques

Because early demonstration projects showed RAP slurry sealing and microsurfacing require pneumatic tire rolling to set the materials, compaction equipment is required for both processes.[39] Compaction facilitates the bond between the coated particles and the asphalt emulsion. Rolling begins after the initial emulsion set but prior to reopening the lane to traffic. For a slurry seals, this can be 4 h after application. For microsurfaces, rolling also begins after initial emulsion set but within the 1-h timeframe before reopening the lane to traffic.[40]

Aluminum sulfate is an additive that retards the reaction between the aggregate and emulsion in virgin mixtures, but for RAP slurries, aluminum sulfate aids in coating and workability. Increasing the aluminum sulfate content increased the set time and delayed reopening the lane to traffic.[41] The construction crew can adjust the aluminum sulfate content added at the paver to improve mixing and set time up to the limit established during the mix design process.

Pavement-Preservation Treatment Performance

PPTA officials monitored the performance of many RAP applications since 2007.[42] Pavement-preservation treatments using RAP performed as good as or better than those using virgin aggregate.

After fractionation, the coarse chips were substituted for virgin aggregate in chip seals, and the fine fraction was substituted for virgin aggregate in slurry seals or microsurfaces. Test sections performed well, convincing agencies that substituting RAP for virgin aggregate provided an equally effective material for pavement-preservation treatments. These successful demonstration projects paved the way for broader acceptance and use of RAP within southern California. As more agencies gained interest, material and application specifications were developed to permit using RAP in chip and slurry seals.

A benefit of using RAP as the aggregate source in slurry seals is a higher total asphalt content compared to virgin mixes—even though less emulsion is required to reach optimum design properties. The increased asphalt content provides better resistance to cracking and raveling and results in smoother surfaces and better-bonded longitudinal seams.[43]

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[38]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[39]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[40]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[41]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[42]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[43]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.

Slurry seals and microsurfaces with RAP performed equally to those without RAP, and RAP chip seals had better chip retention than those using virgin aggregate. The PPTA applied its first RAP chip seal test section in 2004 and it remained in service through 2018 (figure 43). The oldest known in-service RAP slurry and microsurface treatments were applied in 2007 and 2011, respectively. The early success of RAP chip and slurry seals led to large-scale adoption within southern California.[44]

Source: FHWA.

Figure 43. Photo. PPTA's first RAP chip seal test section.

Cost Impacts Attributed to Using RAP as a Material Source

RAP slurry seals and microsurfaces requiring less emulsion than virgin aggregates saved contractors money. However, the savings were partially offset by costs for additional pneumatic tire rollers and customizing emulsions and admixtures.[45] Since pavement-preservation treatment specifications already require the use of polymers and pneumatic tire rollers, cost savings from using RAP can be calculated by the amount of emulsion saved. RAP has a value of $30 per ton and the emulsion has a value of $600 per ton, so using 2 percent less emulsion saves a contractor $11.40 per mixture ton—or roughly $0.10 per sq yd once applied—approximately 4 percent of the material cost.

[44]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[45]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

Product balance also affects contractor costs. When fractionating typical RAP piles, chips represent approximately 40 percent of the total, with the remaining 60 percent separated as a source material for slurry seals or microsurfaces. The typical application rate for chip seals is 28 to 30 lb/sq yd, while the application rate for RAP slurry seals is 18 lb/sq yd. Since 2013, market demand increased for both chip and slurry seals, but demand for coarse chips outpaced demand for the fine fraction. The PPTA accumulated a surplus of RAP fines over the past few paving seasons (figure 44). The imbalance in market demand for materials increased the value of chips compared to fines and impacted the PPTA's pricing structure.[46]

Source: FHWA.

Figure 44. Photo. Market demand causes an imbalance between coarse chip and fine fraction availability.

Challenges/Opportunities Using RAP Treatments

While the PPTA was successful applying pavement-preservation treatments using RAP, challenges and opportunities for improvement exist. Double chip seals, heavy truck traffic areas, and slower microsurface set times prove challenging, while good customer service and safeguarding their application performance remain a primary focus.

Some double RAP chip seals resulted in bleeding. While some bleeding occurred as angular aggregate was manipulated into the flattest profile, PPTA officials witnessed multiple double

[46]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

chip seals bleed excessively under traffic.[47] With emulsion binder applied and a medium-sized RAP chip seal, PPTA officials believed the asphalt coating on the particles contributed to the bleeding. In such instances, PPTA officials recommended placing one layer of RAP chips and one layer of virgin aggregate.[48]

Busy and narrow roadways were challenging for the PPTA regardless of the type of pavement-preservation treatment. Maneuvering applicators around cul-de-sacs resulted in uneven application, and loaded vehicles turning on pavement-preservation treatments dislodged aggregate and created shear marks in the pavement surface. Significant handwork was required on busy and narrow roadways.[49]

Asphalt-coated RAP particles were less reactive with the asphalt emulsion compared to virgin aggregate. Specifically, the dust (i.e., particles smaller than a No. 200 screen) in RAP is coated with asphalt and adhered to other particles, making the active surface area of the blended material less than that of typical virgin aggregate used in slurry seals. Slurry seal set times were inversely proportional to the reactivity between the asphalt-coated RAP particles and the asphalt emulsion (i.e., when reactivity increased, set time decreased). Because microsurfaces are typically used on high-volume roadways or to fill ruts in multiple lift applications, shorter lane-closure zones are preferable. A reliable set time under 1 h from application to reopening to traffic is often required, and there are penalties if the lane is not reopened to traffic in the allotted time. Using a highly modified emulsion or admixture combination helps ensure a reliable set time, but the issue may not be revealed until construction due to normal production variances.[50]

According to the PPTA president, customers expected a contractor to stand behind a product applied and provide solutions when a product fails expectations. One approach was to find and resolve problem areas before they drew attention. Reapplication or touch-up work was sometimes required, but not more frequently than treatments using virgin aggregate. The application crew took the steps necessary to achieve a smooth, uniform texture for RAP slurry seals for their customers (figure 4).[51]

Conclusions

Employees of the PPTA include early innovators of using RAP in pavement-preservation treatments. Many improvements were made in the processes for managing stockpiles, applying both chips and fines, and addressing potential performance issues. By offering RAP materials and pavement-preservation treatments using RAP, the PPTA opened a supply chain for system owners that increased competition, lowered costs, and helped them achieve sustainability goals.

[47]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[48]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[49]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[50]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.
[51]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

CHAPTER 4. CONCLUSIONS AND NEXT STEPS

THE CASE FOR RAP

As documented in the case studies, multiple agencies, including NMDOT, LAC, and SBC, used RAP in pavement-preservation treatments for a variety of reasons. Additionally, several agencies reported either experimenting with or adopting using RAP in pavement-preservation projects. State departments of transportation (DOT), including North Dakota and Pennsylvania, and local DOTs, including Owego, NY, and Trumbull County, OH, used RAP chip seals, while Texas DOT used RAP slurry seals. Increasing numbers of RAP users suggests using RAP in pavement-preservation treatments will continue growing. Based on the case studies, this section identifies key reasons to increase using RAP in pavement-preservation treatments and recommends future research.

RAP Is There

Agencies and contractors both stockpile RAP as a byproduct of milling asphalt surfaces and producing excess material at asphalt plants. Most RAP owners are eager to cost-effectively reuse RAP in as many projects as possible if it does not jeopardize performance or service life. RAP was used in asphalt paving mixtures for decades, but using RAP in pavement-preservation treatments was comparatively new. During the last decade, using RAP in chip seals, slurry seals, and microsurfaces (which are less common) increased, reducing growing stockpiles and contributing to more sustainable pavement-preservation treatments by reducing the need for virgin materials.

RAP Addresses Policy Initiatives

For LAC, using RAP fit into their overall approach to sustainability. LAC had a three-pronged approach to implementing sustainable practices: preserve, reuse, and fortify (LAC 2018a). Preservation strategies included using pavement-preservation treatments to either maintain good conditions or to “freeze” the deterioration of fair- and poor-condition pavements. As part of their reuse strategy, RAP treatment trial sections were applied around 2009 and provided equivalent performance compared to virgin treatments. Approximately 35 percent of LAC’s 2018 pavement-program budget was used to apply RAP pavement-preservation treatments on 152 mi of roadway.[1]

RAP Is Cost Effective

SBC began allowing RAP as a substitute for virgin aggregate in chip seals in 2014 and applies chip seals to approximately 200 centerline-miles on their network annually. Bid results showed allowing RAP as a substitute for virgin aggregate reduced aggregate costs by up to 30 percent. RAP chips had a lower loss tendency and a smoother surface texture than virgin aggregate.

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[1]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan, August 8. Alhambra, CA.

Overall, performance characteristics were similar for chip seals using RAP and those using virgin aggregate.

NMDOT also used RAP chip seals in pavement-preservation projects. UNM conducted research and concluded using RAP in chip seals was the most beneficial way for NMDOT to use RAP. The performance of RAP chip seals was equivalent to that of virgin chip seals. NMDOT had abundant RAP tonnage accumulated after many resurfacing projects, and the millings were stockpiled at State ROW convenient locations. Without RAP, scarce virgin aggregate was procured with haul distances of over 100 mi.

RAP Ownership

Market forces must align for a successful industry to exist. This requires both the need for a product and its supply. The largest roadblock facing using RAP in pavement-preservation projects was disagreement over who owns the RAP. If agencies had access to RAP the owner considered a surplus product with little salvage value, then RAP can be a successful alternative to virgin aggregate. Most State DOTs allow milling contractors to take ownership of RAP to reduce removal and disposal costs. If RAP was owned by those who saw greater value in it than aggregate replacement or those less inclined to provide the material for whatever reason, RAP cannot be an economical alternative for pavement-preservation treatments. Asphalt mixture suppliers saw value in RAP from the aggregate value and the asphalt coating on the aggregate. Asphalt mixture providers have incentive to withhold alternative treatment options. Using RAP in pavement-preservation treatments became common in many cases where the ownership of RAP millings remained the property of the agency or became the property of businesses that did not produce asphalt mixtures.

Using RAP in Pavement-Preservation Treatments

RAP was used in chip seals, slurry seals, and microsurfaces, but the requirements were different for each. In either case, the RAP must be crushed and screened into single-sized coarse aggregate and fines. Yield varies somewhat based on the RAP source and the desired coarse aggregate size, but fractionation typically yields 40 percent coarse RAGG and 60 percent fine RAGG.[2] Proper material testing and mix design were important in determining whether a RAP stockpile was a viable source. RAP stockpiles containing soil or geotextile fabric were unsuitable.

Agencies observed RAP treatments performing comparably to virgin aggregate treatments when care was taken during material selection and application. Some contended that RAP treatments performed better than virgin treatments, although the explanations were not scientifically validated. Asphalt coating the RAP can cause changes in treatment performance. Although adjustments were made to account for the asphalt content from RAP, the optimum asphalt content was still higher considering the virgin emulsion and residual asphalt content. Incorporating too much asphalt in chip seals, slurry seals, and microsurfaces increased bleeding under loads. Alternatively, higher asphalt contents also increased resistance to aging, oxidation, and raveling.

[2]Employees of a pavement recycling company. 2017. Telephone interview by Gregory Duncan. February.

Benefits of using RAP as a substitute for virgin aggregate included enhanced bonding with the applied binder (LAC, SBC, NMDOT, URC, and PPTA), darker, more uniform surface color (LAC), prolonged resistance to oxidation (URC and PPTA), less chip loss (NMDOT and SBC), and smoother surface texture (LAC). Material application rates were similar for RAP and virgin aggregate (LAC, SBC, NMDOT URC, PTL, and PPTA) and costs were lower using RAP instead of virgin materials (SBC and NMDOT).

Chip Seal

RAP can be substituted for virgin aggregate if the RAP stockpile is fractionated to separate the coarse particles for chip seals and the fines for microsurfaces or slurry seals. RAP stockpiles cannot have metal, fiber, or soil contamination; source aggregate properties must meet additional requirements based on the treatment type.[3]

Chip seal emulsion and application rates for RAP treatments required little alteration from those used for virgin treatments and performed comparatively.[4] LAC developed specifications for using RAP in pavement-preservation treatments, while other agencies (i.e., NMDOT, SBC) used typical design and construction specifications with RAP controls added. Without defined design processes, these agencies relied on crew supervisor experience to determine application rates for chip seal binder and aggregate in the field.[5] Some agencies in southern California permitted direct substitution of RAP for virgin aggregate without contract modification.[6]

Several standard- and agency-specific tests were performed to approve source aggregate and emulsion for chip seals. Agencies tested RAP chip seals against many of the same standards that traditionally applied to virgin chip seals. These tests and standards included the following:

- Compatibility testing (e.g., ASTM D7000 [ASTM 2019a]).
- Gradation and sizing for chip seals and slurry seals.
- Cleanliness and sand equivalent values.
- Requirements to be free of detrimental quantities of deleterious materials.
- Abrasion tests (i.e., performance wear at 500 revolutions).
- Methods for determining emulsion and aggregate application rates.
- Requirements and grade selections for emulsions (e.g., polymer-modified, tire-rubber-modified).

Several studies presented anecdotal evidence that chip seals using fractionated RAP perform equivalently to those using virgin materials. The URC monitored the in-service performance of RAGG and precoated virgin aggregate chip seals. Crack mapping, surface texture evaluating, and SN40 testing were performed periodically for each test section. There was minor low-severity cracking and slight wheelpath rutting on both test sections. While there was no significant chip loss on the RAP section, there was chip loss on the precoated aggregate chip test section. SN40 was similar during the first year of loading but decreased for the RAP section as

[3]Manager of a PTL. 2018. Interview by Gregory Duncan. April 26.
[4]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. August 7. Daggett, CA.
[5]Employees of NMDOT. 2018. Interview by Gregory Duncan. May 16. Albuquerque, NM.
[6]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

loading increased. Surface texture measurements for both sections were equivalent. The RAP section performed as well as or better than the adjacent precoated chip section in all measures except SN40.

NMDOT used RAP removed from roadways where SN40s were equivalent for RAP and virgin chip seals. Lower than optimal pavement friction was a concern for agencies when RAP consisted of more than just surface mixtures or where the aggregate source for other mixtures was not a surface-approved material. Chip seals were known to increase surface friction due to the aggregate grading and macrotexture, but based on their mineral composition, the aggregate particles were prone to polishing. SBC was successful applying fog seals to the chip surface to minimize chip loss and color the pavement surface uniformly black.

Slurry Seal and Microsurface

Fewer agencies used RAP slurry seals and microsurfaces than used RAP chip seals. RAP slurry seals and microsurfaces had similar design requirements to RAP chip seals but more restrictive material specifications and more equipment requirements during application. Agencies like LAC specified RAP slurry seals and microsurfaces. RAP slurry seals became the most commonly used pavement-preservation treatment on residential roadways, while RAP microsurfaces were applied less commonly and strictly on arterial roadways with higher traffic volumes.[7] The mix designs for RAP slurry seals and microsurfaces required approximately 1 to 2 percent less emulsion content for optimum performance than RAP chip seals.[8,9] Two factors contributed to a lower required asphalt content: particles were partially coated with asphalt and did not require emulsion to penetrate the voids between particles and the combined RAP blend had less surface area than the combined virgin aggregate blend because it contained fine aggregate conglomerates with fewer free fines (i.e., material passing the No. 200 sieve).

Additional requirements and adjustments agencies established for RAP slurry seals and microsurfaces included the following:

- Lower WTAT values (ASTM D3910, ISSA TB-100 [ASTM 2015b; ISSA 2018a]).
- Equivalent ISSA TB-109 values (ISSA 2018b).
- Required PM-CQS-1h.
- Required higher residual asphalt content in resulting mixtures.
- Higher quality aggregate (demonstrated by wear and sand equivalent tests).
- Field sampling for WTAT (e.g., LAC reduced pay if field sample testing showed loss greater than 50 g/sq ft).
- Required pneumatic tire rolling before reopening to traffic.

Cost Implications

Availability, project site proximity to stockpiles, improved aggregate supply, and willing material owners were some of the variables making using RAP less expensive than virgin

[7]Employee of LAC Department of Public Works. 2018. Interview by Gregory Duncan. August 8. Alhambra, CA.

[8]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.

[9]Manager of a PTL. 2018. Interview by Gregory Duncan. April 26.

aggregate. These factors combined to provide more competition for agencies allowing RAP substitutions for virgin aggregate (i.e., 40 percent by NMDOT, 20 to 27 percent by SBC). Agencies specifying only RAP paid more for treatments due to the same factors (LAC).

For RAP slurry seals, contractors saved money because of the reduced emulsion demand. However, considering additional construction requirements, such as rolling and emulsion customization, cost savings were partially offset.

Construction Considerations

Rapidly progressing technology allowed RAP to be analyzed and implemented in multiple preservation treatments. In New Mexico, portable high-frequency screens made it practical for remote RAP stockpiles to be fractionated and used as high-quality aggregate sources.

Construction oversight (i.e., QC/QA) from internal project inspectors or third-party consultants was conducted regardless of what treatment type was applied. At a minimum, inspectors perform compatibility tests to ensure source materials will combine adequately with the emulsion materials, perform daily gradation tests to ensure material consistency, document crew actions justifying any field adjustments, verify material properties in accordance with the mix design, and monitor application rates to verify calibration and pay quantities.

Bleeding in chip seals was a common deficiency due to improper curing time of pretreatment crack filling, excessive asphalt application rates, chip loss after placement, or flat or elongated particles orienting under traffic. These issues were addressed differently from agency to agency based on experience and material properties. Double RAP chip seals tended to bleed even when the best installation practices were followed.[10] The PPTA recommended that, when double chip seals are specified, at least one layer use virgin aggregate.

Like virgin treatments, SBC recommends filling cracks 6 mo before applying a chip seal and allows scrub seals in lieu of crack filling when cracking is widespread. A scrub seal fills the cracks and the application of RAP chips and a fog seal finish the pavement-preservation treatment.

NMDOT allows crew leaders to set application rates in the field because they vary based on preapplication pavement condition rather than the asphalt content of RAP. Pavements with more extensive oxidation or weathering require a slightly higher binder application rate. In SBC, a there was a slight reduction (i.e., 0.01 to 0.02 gal/sq yd) in binder application rate for RAP chip seals compared to virgin chip seals because the RAP adheres better to the binder.[11]

LAC RAP slurry applications specify rolling with a minimum of three passes with a pneumatic tire roller. Rolling occurs approximately 4 h after application—after the emulsion breaks but before reopening the roadway to traffic. The compactor seats the mixture, which enhances the emulsion's bond to the RAP particles after rolling.

[10]President of a PPTA. 2018. Interview by Gregory Duncan. August 9.
[11]Employee of SBC Department of Public Works. 2018. Interview by Gregory Duncan. August 7. Daggett, CA.

Recommended Research

Using RAP in pavement-preservation treatments advanced over the past decade through innovations of both contractors and owners seeking cost-effective and environmentally sustainable strategies for managing pavements. As using RAP expands into other treatments and parts of the country, more experience specific to different conditions is needed.

Characterizing RAP Asphalt and Emulsion Interaction

It was not well understood exactly what the asphalt-coated particles in RAP contributed to mixtures. RAP-asphalt aged to various degrees while in service and was not be expected to perform like virgin asphalt or freshly produced asphalt emulsion. Practitioners needed more information and guidance on how RAP asphalt interacts with emulsions and other treatments. There were minimal impacts to application rates and performance for most RAP chip seals; however, when multiple RAP chip seals were applied, they were more susceptible to bleeding and flushing. Asphalt-coated particles or a breakdown of the conglomerates that are part of the RAP chip structure were to blame for any bleeding and flushing.

Long-Term Performance of RAP Treatments in Multiple Climate Zones

While LAC monitored RAP pavement-preservation treatments since 2009, no agency documented the performance of a full generation of chip or slurry seals. The expected service life of virgin pavement-preservation treatments is 7 to 10 yr. Future research should document whether RAP treatments meet or exceed service life expectations and whether RAP treatments can be covered with second-generation RAP treatments. Verification is also needed to show RAP slurry seals are viable in climates outside the arid southwestern United States. Trial mix designs were created using source materials from other regions, but widespread national trials were not documented. Some practitioners speculated arid-climate base asphalts were more suitable for reuse because pavements in this climate endure significant aging and weathering. Higher residual penetration values (e.g., greater than 30) indicated adjustments to emulsion sources were necessary to meet design criteria. Softer residual asphalt was more sensitive to virgin emulsion and contributed more binder characteristics to the mixture properties.

Using RAP in pavement-preservation treatments expanded rapidly, and evidence shows RAP performs equivalently to virgin materials. Agencies presented in the case studies all anticipated increased use of RAP in pavement-preservation treatments as part of their pavement-management strategies.

APPENDIX A. LAC RAP PAVEMENT-PRESERVATION SPECIFICATIONS

The following special provisions supplement and amend the SSPWC. As a reference convenience, these special provisions were arranged in a format that parallels the SSPWC. The special provisions are available online at: https://pw.lacounty.gov/gmed/lacroads/Docs/Section_R_2015.pdf#page=188&view=FitB.

The full project specifications are available online at: https://pw.lacounty.gov/gmed/lacroads/TreatmentSlurrySeal.aspx.

APPENDIX B. PPTA RAP SLURRY SEAL SPECIFICATIONS

The following RAP slurry seal specifications were developed and provided by a PPTA.

The RAP slurry specifications are available online at:
http://pavementrecycling.node.a8b.co/pdf/rap-slurry-spec.pdf.

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