Design of Microsurfacing and Chip Seal Mixes with RAP for Local Roadway Application


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16. Abstract

As aggregate resources are depleted, there is a need to turn to more sustainable resources and alternatives to virgin aggregate for pavement preservation treatments. A recent NAPA survey (Williams et al., 2019) shows more RAP is stockpiled in Ohio than any other state, with a total of 11.2 million tons of RAP in 2018. Given the large quantities of RAP in Ohio, and the use of chip seal and microsurfacing for pavement preservation of local roadways, there is a need to determine if RAP can provide a cost-effective alternative to virgin aggregate in pavement preservation treatments for local roadways in Ohio. This study was aimed at assessing the availability of RAP in Ohio for this application, as well as the potential cost savings associated with using RAP as an alternative to virgin aggregate in chip seal and microsurfacing treatments. Additionally, as part of this study, a laboratory evaluation of RAP selected for field study was conducted to characterize material properties in the context of chip seal and microsurfacing designs using RAP. Based on these results, chip seal and microsurfacing mix designs were developed using RAP stockpiled by two local agencies in Ohio.

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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 yards	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 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(°F-32)/9 or (°F-32)/1.8	Celsius temperature	°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 or psi	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	35.71	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 (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius temperature	1.8°C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2 or psi

* SI is the symbol for the International Symbol of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1 Project Background

Chip sealing and microsurfacing are commonly used preventive maintenance/preservation treatments. The Ohio Department of Transportation (ODOT) Pavement Preventive Maintenance Program Guidelines identify chip sealing and microsurfacing as effective treatments for restoring friction, preventing water infiltration, and correcting raveling and oxidation. The guidelines also identify chip sealing as an effective treatment for sealing cracks and microsurfacing as an effective treatment to improve ride quality and reduce rutting. Rajagopal (2010) found chip sealing to be a cost-effective treatment in Ohio and microsurfacing to be reasonably effective on the ODOT general system and marginally effective on the ODOT priority system. Chip seals and microsurfacing are inexpensive relative to hot mix asphalt overlays. Recently completed research by Green et al. (2018) found there is also widespread use of chip sealing and microsurfacing by Ohio's local agencies, i.e. counties, townships, and cities. While local agencies reported chip seals as an effective pavement preservation treatment, many reported high costs and in some regions, limited availability of quality aggregate. As such, many agencies adopted ODOT Construction and Material Specifications (CMS) with exceptions to aggregate gradation requirements.

As aggregate resources are depleted, and the need for aggregate for pavement preservation treatments increases as a result of deteriorating infrastructure and decreasing budgets, there is a need to turn to more sustainable resources. During the annual Ohio Transportation Engineering Conference in 2018, the shortfall of quality aggregate in Ohio was highlighted with three presentations dedicated to aggregate supply and demand in Ohio (Shively, 2018; Cronin, 2018; and Barger, 2018). While aggregate supplies are falling short it is becoming more and more difficult to provide new sources of aggregate due to the years long process with seemingly prohibitive steps required to open a new surface mine (Barger, 2018). This will have a direct impact on availability and cost of aggregate for chip seal and microsurfacing at the local level.

One of the Federal Highway Administration's (FHWA) goals is to improve the sustainability of pavement. To support this goal, FHWA is providing guidance through their Sustainable Pavement Program [https://www.fhwa.dot.gov/pavement/sustainability/] on the use of reclaimed material. Reclaimed Asphalt Pavement (RAP) has been used extensively by the hot mix asphalt (HMA) industry to conserve non-renewable natural materials and reduce cost. According to a recent survey by the National Asphalt Pavement Association (NAPA) (Williams et al., 2019) in 2018 an estimated 101.1 millions tons of RAP was accepted by asphalt producers in the United States. Of the RAP accepted, 82.2 millions tons was used in new asphalt mixtures. Other uses of accepted RAP were reported as aggregate (6.4 million tons), in cold-mix asphalt (0.3 million tons) and other (2 million tons). The survey also showed more RAP is stockpiled in Ohio than any other state, with a total of 11.2 million tons of RAP estimated to be stockpiled across the state in 2018 (Williams et al., 2019). One cost-effective use of excess RAP may be in the construction of chip seals and microsurfacing treatments in place of virgin aggregates.

Laboratory research has shown the feasibility of using different proportions of RAP and 100% RAP in microsurfacing (Robati et al., 2013; Garfa et al., 2016; Poursoltani and Hesami, 2018; Wang et al., 2019; and Yang et al., 2019). RAP has been used in pavement preservation treatments in Los Angeles (LA) County, California dating back to 2008 (Updyke and Ruh, 2016). It was reported numerous projects completed in LA County using RAP chips for scrub seals and chip seals have performed well over the years. More recently, RAP aggregate has been used in polymer-modified slurry seals in LA County, although RAP aggregate use has been limited in microsurfacing (Updyke and Ruh, 2016). In the western parts of the U.S., the use of RAP in chip seals has been reported in the City of Bakersfield, California (Hitti, 2014), San Bernardino County, California (Emerson, 2015) and Mohave County, Arizona (Lasham et al., 2018); by

California Department of Transportation (CalTrans) maintenance division (Emerson, 2015), and by New Mexico Department of Transportation (Tarefder and Ahmad, 2018). Most recently, a study was completed for Pennsylvania Department of Transportation (PennDot) on using RAP as coarse aggregate in bituminous seal coats (Jahangirnejad et al., 2019). While the use of RAP in pavement preservation treatments such as chip seals and microsurfacing has shown to be feasible, studies have been limited, particularly for climates similar to Ohio and for RAP in microsurfacing. Given the large quantities of RAP in Ohio, and the use of chip seal and microsurfacing for pavement preservation/maintenance of local roadways, there is a need to determine if RAP can provide a cost-effective alternative to virgin aggregate in pavement preservation treatments for local roadways in Ohio. Research is needed to verify the availability of RAP material in Ohio and its suitability for use in chip seals and microsurfacing. Further, a field experiment is needed to validate the constructability and performance of mixtures containing RAP aggregate.

2 Research Context

A literature search identified the use of RAP in pavement preservation treatments, namely chip seals and microsurfacing, as well as scrub seals and slurry seals. However, only chip seals and microsurfacing treatments are commonly used in Ohio on local roadways. Although information pertaining to the use of RAP in all of these treatments are summarized in the literature review, this study focuses primarily on the use of RAP in chip seal and microsurfacing treatments.

The ODOT Pavement Preventive Maintenance Program Guidelines defines chip seals as "…sprayed application of… asphalt binder covered immediately by a washed… aggregate, and rolled with a pneumatic roller" (ODOT, 2001). Several procedures exist for determining the proportion of materials in chip seals. Commonly used procedures include the Kearby Method, the method currently used by the New Zealand transportation authority and the McLeod method, which is used by most state highway agencies in the United States. These procedures are described in detail by the proposing researchers in Green et al. (2018). Recommended performance guidelines for chip seal are described by International Slurry Surfacing Association (ISSA) A165.

The ODOT Pavement Preventive Maintenance Program Guidelines defines microsurfacing as "… a thin surface, cold applied paving mixture composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and other additives" (ODOT, 2001). The mix design procedure is described in ASTM Standard D 6372 and performance guidelines described by in ISSA A143. Use of RAP in microsurfacing has been reported in limited applications in California (Updyke and Ruh, 2016) and laboratory studies (Robati et al., 2013). Most recently, FHWA published a study on the use of RAP in pavement preservation treatments in which it was reported RAP microsurfacing is typically applied to arterial roadways which have greater traffic volumes than residential roadways in LA County (Duncan et al., 2020).

2.1 Laboratory Investigations

A comprehensive laboratory study was completed on the use of RAP in slurry seal by Saghafi et al. (2019) in which test results for a slurry seal mixture comprised of virgin aggregate were compared with results for a slurry seal mixture containing 87.5% RAP and 12.5% virgin aggregate (pass the No. 100 sieve). The use of RAP in slurry seal was found to be feasible. The researchers reported improvements in performance over the 100% virgin aggregate control mix based on six laboratory tests and as much as 14% in cost savings when compared with virgin aggregate attributed to a reduction in asphalt binder for the RAP (at 87.5%) slurry mix. Additionally, Saghafi et al. (2019) recommended rolling the RAP slurry seal to improve embedment of RAP into the mat and improve friction.

Several laboratory studies (Robati et al., 2013; Garfa et al., 2016; Poursoltani and Hesami, 2018; Wang et al., 2019; and Yang et al., 2019) have been completed on the use of RAP in microsurfacing mixes, dating back to 2013. Results show using as much as 100% RAP in microsurfacing mixes is feasible and may result in a reduction of asphalt emulsion required, although set time was found to be affected by RAP content.

While the use of RAP in chip seals has been documented in the field, particularly in the western part of the United States, few laboratory investigations have been documented.

2.2 Field Applications

Through the literature search a list of agencies which have constructed pavement preservation treatments using RAP were identified and are listed in Table 2-1.

Table 2-1 Agencies/Organizations having experience with pavement preservation treatments containing RAP

Agency/Organizations	Treatments with RAP	Source
Caltrans Maintenance	Chip seal	(Emerson, 2015)
City of Bakersfield, CA	Cape seal	(Hitti, E., 2014)
City of Colton, CA	Slurry seal	(Udelhofen, 2008)
City of Port Hueneme, CA	Microsurfacing	(Metcalf, 2016)
Los Angeles County, CA	Scrub seal, microsurfacing, slurry seal	(LA County Department of Public Works, 2015; Updyke and Ruh, 2016)
Mohave County, AZ	Chip seal	(Emerson et al., 2018)
National Center for Asphalt Technology (NCAT) at Auburn University	Chip seal	(Kessler et al., 2019)
New Mexico Department of Transportation (NMDOT)	Chip seal	(Tarefder and Ahmad, 2018)
Pennsylvania Department of Transportation (PennDOT)	Chip seal	(Jahangirnejad et al., 2019)
San Bernardino County, CA	Chip seal	(Emerson, 2015)

2.2.1 Chip Seals and Scrub Seals

Emerson (2015) reported RAP used as an aggregate in chip seal in 2006 in San Bernardino County, California, and by Caltrans Maintenance for chip sealing ramps. RAP chips have been used in LA County, California dating back to 2008 in which a half-mile section of scrub seal using RAP was placed (Updyke and Ruh, 2016). LA County has since placed several chip seal and scrub seals using RAP chips and polymer modified rejuvenating emulsion and reported good performance (Updyke and Ruh, 2016). Using specifications from LA County Department of Public Works as a basis for developing their designs, PennDOT began using RAP successfully as coarse aggregate for chip seals (Jahangirnedjad et al. 2019). The RAP was processed to a #8 size. PennDOT reported a savings of $15.00 per ton (a cost savings of about 35%) compared to the cost of virgin aggregate (Jahangirnedjad et al. 2019). Jahangirnedjad et al. found the performance to date of chip seals constructed with RAP was similar to chip seals placed with virgin aggregate.

In 2013, LA County placed a hot-applied chip seal using RAP chips and hot-applied PG 76-22 tire rubber modified asphalt to determine if non-preheated RAP chips would impact adhesion between chips and binder (Updyke and Ruh, 2016). Despite issues encountered related to moisture content, cleanliness of the RAP, and adverse weather conditions during placement, the treatment has performed well. A hot applied chip seal using RAP was also placed in Bakersfield, California in 2013, using a PG 76-22 tire rubber and 3/8-inch RAP chips (Hitti, 2014). During the design phase, comparisons were made between chip seals with RAP and virgin aggregate, and emulsion and hot-applied binder. Additionally, the use of preheated versus non-preheated aggregate was investigated. It was concluded the non-preheated RAP chip performed as well as virgin aggregate. The hot-applied RAP chip seal was then capped with a Type II RAP slurry seal forming a cape seal. Hitti (2014) reported after one year of traffic the cape seal was performing well with no signs of distress reflecting or aggregate loss.

2.2.2 Slurry Seals and Microsurfacing

LA County has placed (and has a written specification for) RAP slurry seal using polymer modified emulsion (Updyke and Ruh, 2016), and RAP microsurfacing (Duncan et al., 2020). Based on their experience with RAP slurry seals, Updyke and Ruh concluded, the benefits of RAP are reduced virgin binder content due to residual asphalt content of the RAP aggregate, lower absorption rate, and wet track abrasion test results similar to mixtures without RAP. They reported a pneumatic-tired roller was required after placement of the RAP slurry seal. They also found the use of aluminum sulfate resulted in a much higher loss of aggregate in the wet track abrasion test than RAP slurry seal made with Portland cement additive (Updyke and Ruh, 2016). Updyke and Ruh (2016) also reported LA County has used RAP in microsurfacing to a lesser extent with positive results.

2.3 Objectives

This research project consists of an assessment of the availability and feasibility of using RAP in microsurfacing and chip seal mixes. Specific objectives include:

- Assess the availability of RAP in the Ohio market
- Conduct a laboratory evaluation of the properties of RAP for use in microsurfacing and chip sealing.
- Determine the cost benefit of using RAP for aggregate in microsurfacing and chip sealing
- Design a field experiment to evaluate the effect of RAP on the properties and performance of microsurfacing and chip seal mixtures.

2.4 Tasks

The primary goal of this research study was to assess the availability and feasibility of using reclaimed asphalt pavement (RAP) in chip seal and microsurfacing. The availability of RAP for application in pavement preservation treatments has been addressed in a separate section of the report. To evaluate the feasibility of using RAP a four-pronged approach was taken. First, a literature search was conducted to identify completed or active research, trade magazine articles, presentations pertaining to the use of RAP in pavement preservation treatments. Next, a questionnaire was sent to practitioners across the country who were identified through the literature search to have experience placing or designing preservation treatments with RAP. This included representatives from state and local agencies, material suppliers, contractors, and researchers. In some cases, a phone interview was conducted in addition to or in lieu of the participant completing the questionnaire. Third, a laboratory investigation was conducted to evaluate RAP characteristics pertinent to chip seal and microsurfacing. Lastly, chip seal and microsurfacing mix designs were developed using RAP from two Ohio local agencies. Findings from the literature search and questionnaire/phone interviews are provided in this section. Requirements related to RAP properties for use in chip seal and microsurfacing which were identified through the literature search or provided by practitioners are presented along with the results of the laboratory characterization of RAP in a separate section. Lastly, completed laboratory testing and results associated with the development of mix designs for chip seal and microsurfacing mixes using RAP are presented in a separate section.

To fulfill the objectives listed above, the following tasks were undertaken as part of this project:

1. *Conduct a literature search.* A literature search was conducted to help identify completed and active research pertaining to the use of RAP in pavement preservation treatments. Focus was placed on the use of RAP in chip seal, Otta seal, and microsurfacing (polymer modified slurry seal) applications. Information related to physical properties of RAP specific to these applications was sought. The impact of RAP in chip seal, Otta seal, and microsurfacing (polymer modified slurry seal) on mix design procedures, quality assurance, quality control, and cost effectiveness was also sought.

   Based on the findings of the literature search, pavement preservation treatments incorporating RAP have been placed or studied by the following agencies/organizations in the U.S.:

   - Caltrans Maintenance (Emerson, 2015)
   - City of Bakersfield, CA (Hitti, E., 2014)
   - City of Colton, CA (Udelhofen, 2008)
   - City of Port Hueneme, CA (Metcalf, 2016)
   - Los Angeles County, CA (LA County Department of Public Works, 2015; Updyke and Ruh, 2016)
   - Mohave County, AZ (Emerson and Ford, 2018)
   - National Center for Asphalt Technology (NCAT) at Auburn University (Duncan et al., 2020)
   - New Mexico Department of Transportation (NMDOT) (Tarefder and Ahmad, 2018)
   - Pennsylvania Department of Transportation (PennDOT) (Jahangirnejad et al., 2019)
   - San Bernardino County, CA (Emerson, 2015)

   The research team attempted to contact these agencies or their contractors and materials suppliers to gain additional knowledge on aspects pertaining to the use of RAP in chip seal or microsurfacing, such as RAP material properties, mix design requirements, construction, quality control and quality assurance, and cost effectiveness. Construction and materials specifications were also requested.

2. *Assess current state of RAP supply in Ohio.* To determine if an adequate supply of RAP exists to support the use of RAP in pavement preservation treatments for local roads in Ohio, the research team reviewed results of national surveys pertaining to RAP supply and usage across the country and contacted several asphalt producers in Ohio to gather information related to amount of RAP stored and used, and the methods used for processing RAP. Additionally, an assessment of the amount of RAP generated through ODOT let projects and the amount of RAP utilized in new asphalt pavements was made from contracts awarded by ODOT from 2015 to 2019. The research team also surveyed counties or municipalities to determine the quantity of RAP stockpiled and used by these agencies. Job mix formulas (JMFs) for hot mix asphalt with RAP were obtained from a previous project, "Evaluation of Asphalt Base Course Construction and Acceptance Requirements, Phase 1." The JMFs were reviewed to capture the gradation of RAP stockpiles across each region in Ohio. These gradations were compared to the gradation requirements for

chip seal, and microsurfacing treatments using virgin aggregate to identify the need for additional processing of RAP for use in preservation treatments as an alternative to virgin aggregate.

3. *Assess amount of chip seal and microsurfacing treatments placed on local roadways.* Information from local agencies was collected via an online survey and phone interviews. Additionally, information collected as part of a previous study (Green et al., 2018) was reviewed to enable the research team to assess the potential for using RAP as an alternative to virgin aggregate and the potential cost-savings associated with using RAP in preservation treatments. Based on the responses, counties were selected such that each geographic region of the state was represented to contact for a phone interview for additional information regarding chip seal and microsurfacing treatments. The questions were sent to the agencies prior to the phone interview.

4. *Preliminary cost analysis.* Based on the findings from Tasks 2 and 3, the potential cost-savings associated with using RAP as an alternative for virgin aggregate in chip seal among local agencies in Ohio was estimated. The cost for the estimated quantity of virgin aggregate required for preservation treatments in each was calculated and compared with the estimated cost of the same quantity of RAP.

5. *Presentation of Literature review and supply assessment results*. On August 20, 2020, findings from Tasks 1 through 4 were presented to the Technical Advisory Committee (TAC).

6. *Characterization of RAP.* Laboratory testing was conducted on RAP sampled from Wayne County, and City of Lancaster. RAP gradations were developed for chip seal applications by taking into consideration gradation requirements for RAP chip seal in PennDOT specifications, and requirements for virgin aggregate under AASHTO No. 8 and ODOT Item 422, Type A gradations. Resulting gradations of RAP processing operations were also considered in the selection of the target RAP gradation for chip seal application. Similarly, a RAP gradation for use in microsurfacing was selected based on requirements in LA County's Specifications for microsurfacing using RAP for unextracted RAP, and gradation requirements for virgin aggregate under ODOT Item 421 Type A. Gradations resulting from RAP processing operations were also considered in the development of target RAP gradations. RAP sourced from Wayne County and City of Lancaster was sieved and crushed in the laboratory to achieve the target RAP gradations for each application. Various laboratory tests were conducted for comparison with RAP properties identified in LA County specifications and Greenbook (Standard Specifications for Public Works Construction (SSPWC)) specifications for RAP chip seal and RAP microsurfacing and to support the development of chip seal and microsurfacing mix designs in Task 7. Additionally, virgin chip seal aggregate from Wayne County and virgin microsurfacing aggregate from City of Lancaster were sampled. The same laboratory tests were conducted on the virgin aggregate for comparison with RAP and to support the development of mix designs for the control chip seal and control microsurfacing mix.

7. *Develop and Test Mix Designs for Preservation Treatments with RAP.* Based on the material properties of RAP and virgin aggregate to be used in chip seal and microsurfacing applications determined in Task 6, mix designs were developed for chip seals using 100% RAP for two traffic levels for a route in Wayne County, and for microsurfacing treatments with 100% RAP for a route in the City of Lancaster. Mix designs for chip seal and microsurfacing mixes using virgin aggregates were also developed to serve as the control mixes.

8. *Develop Field Study for Evaluation of Selected Preservation Treatments Constructed with RAP.* Test sites in each agency, City of Lancaster and Wayne County, were identified for the placement of test sections to evaluate the use of RAP as an alternative to virgin aggregate in microsurfacing and chip seal, respectively. Through discussions with the agencies and the TAC locations for the test sites were selected. A plan was then developed for the field evaluation of RAP chip seal and RAP microsurfacing test sections relative to chip seal and microsurfacing treatments placed with virgin aggregate which would serve as the control test sections.

9. *Draft Final Report.* Results and findings from Tasks 1 through 8 of this project were documented in a final report.

3 Research Findings

This section serves as a summary of the key findings from this study. Details and results related to the above tasks are documented in the following sections:

- Literature Review and Interviews with Practitioners
- Analysis of RAP Supply/Demand and Potential Cost Savings for RAP in Chip Seal and Microsurfacing Treatments for Local Agencies in Ohio
- Characterization of RAP for use in Microsurfacing and Chip Seals on Local Roadways
- Design of Chip Seal
- Design of Microsurfacing
- Field Study for Evaluation of Microsurfacing and Chip with RAP Constructed on Local Roadways in Ohio

3.1 Key findings from the Literature Review and Interviews with Practitioners

3.1.1 RAP as an Alternative to Virgin Aggregate in Chip Seal

The use of RAP as an alternative to virgin aggregate in chip seal in the field has been documented, particularly in Pennsylvania (chip seal) and the western part of the country and reports have overall, shown RAP chip seals perform as well or better than virgin chip seals. More specific findings from the literature, the recently published FHWA report on RAP in pavement preservation (Duncan et al., 2020), and responses to interviews and questionnaires conducted for this study are summarized below:

- Regarding the processing of RAP for use in chip seal, Tarefder and Ahmad (2018) indicated pavement millings retained by NMDOT are screened using a portable processing plant using two screens, typically 3/8 in. and 1/2 in., to achieve single sized RAP chips. As a result, RAP chips are greater than 3/8 in. and less than 1/2 in. in size. Particles retained on the top screen (1/2 in.) are crushed and rescreened, while those that pass the 3/8-in. screen are placed in a stockpile for use in other applications. RAP particles which pass the 1/2-in. screen and are retained on the 3/8-in. are used for chip seal.
    - As much as 50 percent of the RAP stockpile was used in NMDOT's coarse RAP chip seal. RAP that is too fine for chip seal gradations were used for cold central-plant recycling, stabilized shoulder maintenance and pipe-bedding material (Duncan et al., 2020)
- Additional costs are associated with RAP chip seal due to the cost to fractionate and haul to the site.
    - However, comparing costs per ton of RAP and virgin aggregate, it was reported (Duncan et al., 2020) that by processing and delivering the RAP to district-wide stockpiles, NMDOT saved more than 40%. Total price of RAP chip seal was estimated at $23.50/ton and virgin chip seal was estimated at $40.21/ton.

    - PennDOT reported processing RAP to a #8 size chip and saw a costs savings of 35% over virgin aggregate when using 100% RAP for chip seals.
- Some fractionated RAP clump together and require rescreening, this is generally the case with RAP fines which have more asphalt binder than the RAP chip particles and when stored long term or under hot conditions.
- Little to no modifications to the design and construction process may be needed when using RAP chips as an alternative to virgin chips.
    - The binder application rate may need to be adjusted depending on the condition of the pavement, or the parent rock of the RAP.
        - Generally, binder application rate for RAP chip seals is reduced slightly relative to virgin chip seals.
        - The parent rock of the RAP is important, if the aggregate is soft, the shot rate should be reduced.
    - Others reported little difference in application rates between virgin and RAP chip seals, but the emulsion formulation for RAP chip seals may differ slightly to account for less reactive aggregate
- It was reported many agencies rely on a contractor's proposed RAP chip seal design rather than specifications for RAP. Additionally, they typically used existing specifications for virgin aggregate with the addition of controls for RAP
- Chip loss was reported to be less with RAP chips than virgin aggregate
    - It was reported the asphalt film on the RAP may enhance bonding and the fine particles may serve as a choke stone resulting in improved texture density and reduction in chip loss
    - Surface texture and bond of RAP chip seals was found to be comparable to that of virgin chip seals.
- Bleeding in RAP chip seals was observed to be similar to virgin chip seals and is due to over application of binder material. However, significant bleeding in the wheelpath was observed by a different agency for a double layer RAP chip seal near an intersection, leading agency personnel to believe the asphalt content of the RAP may have contributed to bleeding more severely than would have been expected with a double layer virgin chip seal.
- Treatments with RAP should be placed at temperatures between 60°F and 105°F to prevent the RAP from becoming tacky and clogging laydown equipment.
    - When applying RAP chip seal, make sure the temperature is not above 120°F to avoid pick up by the delivery trucks.
- One agency reported the advantage of using RAP in chip seal is having consistent size aggregate while the disadvantages are additional testing, additional pavement test strips, oversight, emulsion rate changes, inspections, and post treatment inspections for bleeding.

3.1.2 RAP as an Alternative to Virgin Aggregate in Microsurfacing

Regarding the use of RAP as an alternative to virgin aggregate in microsurfacing, overall, researchers reported replacing all or portions of virgin aggregate with RAP in microsurfacing in the laboratory is feasible and can result in improved performance over 100% virgin aggregate mixes depending on the laboratory test. More specific findings from laboratory investigations are summarized below:

- Garfa et al. (2016) found cohesion improved after a longer rest period, indicating the time to open microsurfacing mixes constructed with RAP in the field is greater than that of microsurfacing constructed with virgin aggregates. Additionally, Garfa et al. (2016) reported the emulsion selected can influence the behavior of microsurfacing made with RAP and recommend the emulsion be adapted to the RAP being used due to the interactions between aged asphalt binder and the asphalt emulsion.

- Poursoltani and Hesami (2018) found mixtures containing more RAP would demand lower amounts of additive to increase the mixing time and workability, which could curtail the cost of material preparation. The test showed an increase in the RAP content used in the mix results in an increase in the required water content and a reduction in the additive content required for the mix.
- Wang et al. (2019) found the optimal asphalt content decreases with an increase in RAP content. This indicates the usage of RAP could reduce the virgin binder content requirement by contribution of the RAP binder and by limiting binder absorption. Therefore, a benefit of using RAP is saving raw materials and cost.
- Poursoltani and Hesami (2018) also reported RAP-containing mixtures needed about 1% more bitumen than those containing virgin aggregate to obtain sufficient cohesion within the specified time period, usually within 1 hour, to open the road to traffic. This seems to contradict such benefits of RAP as reduced virgin binder content due to residual asphalt content of the RAP aggregate reported by Updyke and Ruh (2016) and Wang et al. (2019). However, Poursoltani and Hesami (2018) indicated using more binder is still reasonable because the mixture containing 100% virgin aggregate, in contrast, was more sensitive to the change in bitumen content as more deformation occurred with a small change in the amount of bitumen emulsion used.
- Compaction in the laboratory mix design was proposed by Wang et al. (2019) to improve the rutting resistance and accelerate curing. The researchers compacted the mix manually with a ''U"-shaped steel screed using a sawing action until the vertical displacement did not change. Their test results showed compaction significantly reduces percent vertical displacement and percent lateral displacement. After using rejuvenators and compaction in the laboratory, the rutting resistance of 40% RAP mixtures, which had the worst rutting performance, was better than 0% RAP mixtures. This indicates both compaction and rejuvenating agents are important strategies for RAP microsurfacing mixtures (Wang et al., 2019).
- Wang et al. (2019) reported the hydrophobic nature of RAP may impact the time to break and mixing time for RAP microsurfacing mixes, such that at RAP contents greater than 40% mixing time decreased with an increase in RAP content.

Additionally, practitioners reported the use of 100% RAP as an alternative to virgin aggregate in microsurfacing can have equivalent or better performance than virgin microsurfacing mixes in the field. Although one agency reported bleeding when RAP microsurfacing was attempted. More detailed findings from the recent FWHA report on the use of RAP in pavement preservation treatments (Duncan et al., 2020) and from interviews with agencies, contractors and material suppliers conducted for this study are summarized below:

- When designing RAP slurry seals or microsurfacing the same standards as virgin aggregate slurry seal or microsurfacing are used, although the RAP asphalt content and gradations may differ slightly from mixes with virgin aggregate
- It was reported 100% of virgin aggregate can be replaced with RAP if the RAP is fractionated and graded into coarse particles for chip seal and fine portions for slurry seal or microsurfacing.
    - The RAP stockpile should be free of metals, fibers, and soils.
    - The source aggregate of the RAP should meet agency requirements for aggregate properties of the selected preservation treatment.
    - Processing RAP to a Type III gradation (coarse) is difficult to create consistent gradations and can be costly.

- Gradation of the extracted RAP aggregate should be conducted as there are significant differences between washed and extracted gradation.
    - The gradation of the blend and particle shape affect the optimum emulsion content needed to provide coating and workability.
    - RAP with a Type I (fine) gradation has a high residual asphalt content which can create issues during material handling and processing.
- Using RAP in slurry seal and microsurfacing is complicated. Although it results in 1-2% reduction in virgin asphalt emulsion, the RAP causes the emulsion to not break as quickly (a slower set).
    - The asphalt emulsion can be adjusted to overcome the reduction in set time.
    - Using emulsion for slurry seal or microsurfacing with a 3% polymer modification enhances aggregate retention. RAP slurry seal and microsurfacing mixes use less asphalt emulsion therefore the polymer modifier helps account for time to set.
- If RAP binder is too soft or there is too much RAP binder there can be a significant impact on performance. Too little asphalt from the emulsion could cause early performance issues like raveling.
    - Extracted asphalt binder with penetration values greater than 30 are considered too soft and adjustments must be made by the emulsion supplier.
- A pneumatic tire roller is required for both RAP slurry seal and RAP microsurfacing as compaction helps bond the coated particles and asphalt emulsion.
    - Rolling should begin after the initial emulsion set and prior to reopening the lane for traffic. For microsurfacing this is typically within a one hour timeframe prior to reopening to traffic.
- The increased asphalt content of the fine RAP fraction used in slurry seal and microsurfacing provides better resistance to cracking and raveling, a smoother surface and better bond at the longitudinal joints.

3.2 Key findings from the Analysis of RAP Supply/Demand and Potential Cost Savings for RAP in Chip Seal and Microsurfacing Treatments for Local Agencies

Based on a review of the recent NAPA survey and contract award information for ODOT, there is an abundance of RAP in the state. According to the 2019 NAPA survey (Williams et al., 2019) more RAP is stockpiled in Ohio than any other state, with a total of 11.2 million tons of RAP estimated to be stockpiled across the state in 2018. Using an average RAP usage of 28% in HMA/WMA production, and a conservative mill depth of 1.5 inches (38.1 mm) annual excess RAP ranges from 195,000 tons to nearly 1.2 million tons per year for ODOT projects alone. This indicates asphalt producers in Ohio will not be able to use their entire RAP supply in HMA/WMA alone under ODOT's current HMA/WMA specifications.

Although there is excess RAP in the state, the accessibility to local agencies is of concern. When RAP is generated by pavement milling for ODOT projects, unless otherwise stated in the plans or contract documents, the RAP is retained by the contractor (most often the asphalt producer). As a result, the largest supplies of RAP are housed at asphalt plants around the state. Asphalt producers interviewed in this study reported RAP was sold at FOB plant prices ranging from $20/ton to $50/ton. However, the price local agencies reportedly paid when purchasing RAP tended to be lower, with prices ranging from $5/ton to $25/ton. More than 25% (6 of 22 agencies) of the responding agencies indicated they have purchased RAP in the past, indicating RAP is available to local agencies and is more economical than virgin aggregate in some locations.

Another source of RAP for local agencies is that which is generated by pavement millings from their annual paving projects. Of the local agencies which responded to the question in the survey conducted for this study, 60% (11 of 18 agencies) reported they had stockpiled RAP in 2019, with the amounts reported ranging from less than 500 tons to more than 1500 tons. In addition to the survey and phone interviews conducted with selected counties, the research team understood that some local agencies stockpile RAP themselves. While the research team had knowledge of at least one agency, it was believed far more do so. Therefore, the research team utilized Google maps satellite map views to assess whether RAP stockpiles were visible at each of the 88 county engineers' yards around the state, from which a preliminary list was developed. This list revealed between 44% and 79% of Ohio's counties may stockpile RAP. Based on the number of counties which may be stockpiling RAP, the percent of agencies reporting in the survey that they stockpile RAP can likely be expanded to the wider population of local agencies in Ohio.

To evaluate the amount of RAP that is available and can replace virgin aggregate in chip seal or microsurfacing at the local levels, it is necessary to compare amount of RAP accessible to local agencies to the amount of virgin aggregate used in chip seal or microsurfacing. While RAP may be purchased from asphalt producers, the most accessible and economical source of RAP for local agencies may be through the retention of their own pavement millings. It was found through the results of the survey and phone interviews conducted in this study, the amount of pavement millings vary widely, although the majority of agencies that responded reported amounts falling between 25,000 and 50,000 square yards (SY) per year. For a single local agency, this amounts to an estimated 534 tons to 1,068 tons of RAP generated per year.

Results from a survey pertaining to aggregate used in pavement preservation treatments issued to local agencies as part of this study were used to assess the demand of RAP to replace virgin aggregate in chip seal or microsurfacing mixes. However, limited responses were provided for microsurfacing treatments, therefore only the potential demand for replacement of virgin chip seal aggregate was evaluated. In combining an estimated 23 lb/SY of virgin aggregate with estimates of approximately 75,800 SY to 639,500 SY of chip seal placed per year, the potential demand for RAP in chip seals was calculated to be between 871 tons and 7,354 tons per year for a given local agency.

Based on the wide range of pavement milling and chip seal placed each year, it was found 7% (534 tons RAP/7,354 tons virgin aggregate) to 100% (1,068 tons RAP/871 tons virgin aggregate) of the virgin chip seal an agency places in one year can be replaced with RAP chip seal. If the high end of the range of RAP is generated and the low end of the range of chip seal is placed in a year, then excess RAP may exist which can be stored for future use. Although it was assumed for this analysis 100% of the RAP from pavement millings can be processed to meet chip seal gradations, based on literature (Duncan et al., 2020) and interviews with practitioners experienced in using RAP in preservation treatments, when fractionated approximately 40% of the RAP stockpile is coarse and is appropriate for chip seal while the remaining material is fine RAP and is appropriate for microsurfacing.

Cost analyses were conducted to evaluate the potential for cost savings by using RAP as an alternative to virgin aggregate in chip seals and microsurfacing treatments for local roadways. In all analyses, it was assumed 100% of the RAP pile was used such that 30% was used for RAP chip seal and 70% for RAP microsurfacing. A total of three alternatives for sourcing chip seal and microsurfacing aggregate were considered in the following two examples: RAP is purchased from an asphalt producer/contractor, agency retains RAP from an agency project, and agency purchases virgin chip seal aggregate from material supplier and virgin microsurfacing aggregate is included in the cost of construction of virgin microsurfacing. In all cases, the cost to process RAP by contract is assumed to be $10/ton. The following scenarios were considered for the virgin aggregate and RAP aggregate alternatives for each example:

- Example 1:
    - Alternatives for RAP:
        - RAP is purchased from an asphalt producer/contractor
        - RAP is hauled to the agency location
        - RAP is processed by contract for use in chip seal and microsurfacing treatments
        - Agency places chip seal and microsurfacing is placed by contract using the agency's RAP
    - Virgin aggregate:
        - Virgin aggregate is purchased from material supplier for chip seal
        - Virgin chip seal aggregate is hauled to the agency location
        - Agency places chip seal
        - Agency places microsurfacing by contract which includes the cost of virgin microsurfacing aggregate
- Example 2:
    - Alternatives for RAP:
        - Agency retains RAP from an agency project
        - RAP is processed by contract for use in chip seal and microsurfacing treatments
        - Agency places chip seal and microsurfacing is placed by contract using the agency's RAP
    - Virgin aggregate:
        - Virgin aggregate is purchased from material supplier for chip seal
        - Virgin chip seal aggregate is hauled to the agency location
        - Agency places chip seal
        - Agency places microsurfacing by contract which includes the cost of virgin microsurfacing aggregate

It was found in Example 1, when a conservative value of $20/ton for purchasing RAP is used, associated costs of RAP add significant cost to the project, with the RAP alternative costing 25% more than the virgin aggregate alternative. However, if RAP could be purchased for $11.80/ton or less, the overall cost associated with using RAP as an alternative to virgin aggregate in chip seal and microsurfacing would be equivalent or less than the cost of using virgin aggregate. Four of the six agencies which provided a cost for purchasing RAP indicated the price was $12 or less, therefore, purchasing RAP may be an economical alternative to using virgin aggregate.

In Example 2, it was found significant cost savings can be achieved if millings from an agency-owned project can be retained. Costs associated with the RAP alternative in which millings are retained are 52% less than costs associated with using virgin aggregate in chip seal and microsurfacing treatments. Assuming an agency has a situation similar to the scenario and costs presented in the analysis for Example 2, retaining millings from a project is the preferred cost alternative for the three alternatives compared. Based on the assumptions presented in Examples 1 and 2, purchasing RAP from a contractor at costs similar to virgin aggregate is not cost effective for a local agency. In addition, the RAP material generally requires additional processing incurring additional cost.

3.3 Key findings from the Characterization of RAP for use in Microsurfacing and Chip Seals on Local Roadways

Gradations of RAP from historical job mix formulas (JMFs) for asphalt surface, intermediate and base mixtures from across the state were reviewed and compared with gradation requirements for virgin aggregate in ODOT's specifications for chip seal and microsurfacing. It was found RAP, when processed by the asphalt producer for use in asphalt concrete, would need to be further processed for application to chip seal and/or microsurfacing treatments.

The ODOT gradations for chip seal and microsurfacing were compared and appear to be complementary with the chip seal gradation requiring a coarser, more-uniform aggregate gradation while the microsurfacing requires finer materials. Creating a chip seal aggregate from RAP will create left-over fine RAP material that may satisfy the microsurfacing gradation requirements. The combination of using RAP for chip seal and microsurfacing could help utilize the entire RAP gradation and create a valuable use for RAP fine materials.

Target gradations were established for RAP from Wayne County for use in chip seal based on PennDOT gradation requirements of RAP for use in seal coat, and virgin aggregate gradation requirements for ODOT Chip Seal (Item 422, Type A) and AASHTO No. 8. RAP gradations that are feasible based on RAP processing operations were also taken into consideration in establishing the target gradations for RAP for use in chip seal and microsurfacing. In a similar fashion, target RAP gradations were also established for use in microsurfacing based on unextracted RAP gradation requirements in LA County's RAP microsurfacing specifications, and ODOT microsurfacing (Item 421, Type A).

RAP from Wayne County and RAP from the City of Lancaster were processed (fractionated, crushed and fractionated again) in the laboratory to achieve the target gradations associated with each RAP source, Wayne County RAP was utilized for chip seal and City of Lancaster RAP was utilized for microsurfacing. Through screening and the use of a small hammer mill in the laboratory, approximately 46% to 64% of the Lancaster RAP met the target microsurfacing gradation, while 26% to 44% of the Wayne County RAP met the target chip seal gradation. Ranges depend on the amount of crushing conducted in the laboratory, and may not reflect the capability of full-scale operations.

Once the RAP sources were fractionated a range of aggregate tests were conducted for comparison with existing specifications (LA County) for RAP used in chip seal or microsurfacing and for use in mix design of RAP chip seals and RAP microsurfacing mixes. Laboratory testing of RAP representative of the target gradations and virgin chip seal aggregate and virgin microsurfacing aggregate was completed following the tests listed in Table 3-1.

Table 3-1 Laboratory Test Plan for Evaluating RAP for use in Chip Seal and Microsurfacing

Treatment/RAP source	Test	Specification
Chip Seal: RAP (Wayne Co.)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed) ODOT S 1039 (Extracted aggregate)
	Sand Equivalence	AASHTO T 176
	Loose Unit Weight	AASHTO T 19
	Flakiness Index	Tex-224-F and MN Seal Coat Handbook (Wood et al., 2006)
	Specific Gravity of Fine Aggregate	AASHTO T 84/ ODOT S 1031
	Specific Gravity of Coarse Aggregate	AASHTO T 85
	LA Abrasion	AASHTO T 96/ ASTM C 131
	Extraction of Asphalt Binder	AASHTO T 164
Chip Seal: Virgin Aggregate (Wayne Co.)	Sieve Analysis	AASHTO T 27 (unwashed) and AASHTO T 11 (washed)
	Sand Equivalence	AASHTO T 176
	Loose Unit Weight	AASHTO T 19
	Flakiness Index	Tex-224-F and MN Seal Coat Handbook (Wood et al., 2006)
	Specific Gravity of Fine Aggregate	AASHTO T 84
	Specific Gravity of Coarse Aggregate	AASHTO T 85
Microsurfacing: RAP (Lancaster)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed) ODOT S 1039 (Extracted aggregate)
	Sand Equivalence	AASHTO T 176
	LA Abrasion	AASHTO T 96/ ASTM C 131
	Durability Index	AASHTO T 210
	Methylene Blue Vale	ISSA TB 145
	Extraction of Asphalt Binder	AASHTO T 164
Microsurfacing: Virgin Aggregate (Lancaster)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed)
	Sand Equivalence	AASHTO T 176
	Durability Index	AASHTO T 210
	Methylene Blue Vale	ISSA TB 145

Testing was conducted in the laboratory for comparisons with established requirements for RAP for use in chip seal or microsurfacing. Testing was also conducted to determine RAP properties that may be useful in mix design tests. Results compared with the identified requirements are summarized in Table 3-2. Although it is not shown in the table, washed gradations were met for each chip seal and microsurfacing. Furthermore, LA County extracted gradation requirements were also met for RAP in microsurfacing. For the tests completed, as shown all RAP requirements were met for chip seal using Wayne County RAP and likewise, all RAP requirements for microsurfacing were met using Lancaster RAP. Furthermore, where ISSA or ODOT requirements exist for virgin aggregate for the same tests listed in Table 3-2, the tested RAP met or exceeded such requirements. Thus, the use of RAP in chip seal or microsurfacing applications should be feasible, however, additional testing should be conducted to determine if the RAP sources can meet mix design requirements for each application.

Table 3-2 Summary of Test Results for RAP Relative to RAP Requirements

Treatment/ Material	Test	Agency	Requirement	Test Result
Chip Seal: Wayne Co. RAP	Sieve analysis	PennDOT	Table 7-2	Table 7-2
	Sand equivalence	LA County	80, min	99
Microsurfacing: Lancaster RAP	Sieve Analysis	LA County	Table 7-8	Table 7-8
	Asphalt Content of RAP	LA County	6.5%, min.	7.2%
	Durability	LA County	55%, min.	72%
	LA Abrasion (RAP Retained on No. 4 sieve)	LA County	35%, max.	23%
	Sand Equivalence	LA County	60, min.	89

3.4 Key Findings from the Design of Chip Seal Mixes

There are two common methods for chip seal design, the McLeod method and the New Zealand method. The McLeod method focuses on a purely voids approach, where the primary objective is to calculate the void space in the aggregate and fill a certain amount of that space with binder. In contrast, the New Zealand method considers substantially more characteristics of the pavement to make a recommendation on aggregate and binder application rates. Because chip seal mix design is an art and not an exact science, both of these methods were evaluated. Due to the nature of chip seal, field adjustments are expected. Therefore, the selection of the precise application rates will be determined based on field conditions and crew experience at the time of placement. Tables and figures are provided to aid in these field adjustments.

Based on the aforementioned discussion, the research team recommends using the average of the starting application rates from the McLeod and New Zealand methods, as presented in Table 3-3, as the initial aggregate and binder application rates.

Table 3-3 Final recommendation application starting rates for the aggregate and binder chip seal mixes

Road Name	**Location**	**Direction**	**Mix Name**	**Aggregate Application Rate, $\overline{C}$, (lb/yd^2)**	**Binder Application Rate, $\overline{B}$, (gal/yd^2)**
Chippewa	North of Smucker	NB	Virgin Mix 1	27.0	0.36
Chippewa	South of Smucker	NB	Virgin Mix 2	27.0	0.40
Chippewa	North of Smucker	SB	Rap Mix 1	19.6	0.29
Chippewa	South of Smucker	SB	Rap Mix 2	19.6	0.33

The field team may need to adjust onsite. Adjustments are recommended within the range provided by the McLeod and New Zealand method, with additional assistance from Figures 8-2 through 8-5 (McLeod Method) and Figures 8-7 through 8-10 (New Zealand method). The choice of figures should be chosen based on whether the adjusted application rate moves towards the McLeod method or the New Zealand method's recommended values. The field team should also monitor for bleeding, which will reduce skid resistance at the intersection. If bleeding occurs, binder application rate should be decreased to maximize safety. (*Note:* Conversely, binder application rate may need to be increased if there are patches; however, none were observed in the test sections under consideration.)

3.5 Key Findings from the Design of Microsurfacing Mixes

Mix designs for RAP from the City of Lancaster, the proposed location for the field of evaluation of microsurfacing mixes with RAP, were developed as well as microsurfacing mixes with virgin aggregate. The RAP utilized in the mix design process met the target gradation established for the RAP for use in microsurfacing mixes. The virgin aggregate was provided by the City of Lancaster and was thought to be representative of the material they plan to place during the 2021 construction season, including the control test section for the field evaluation. Results of the laboratory testing conducted to support the design of RAP and virgin aggregate microsurfacing mixes are presented in Table 3-4. Also listed in the table are specifications for microsurfacing mix for ODOT Item 421 (virgin microsurfacing mixes), LA county (RAP microsurfacing mixes) and ISSA A143 (virgin microsurfacing mix). RAP (A) refers to the sample with RAP containing 10% emulsion, 8% water and 1% cement while RAP (B) refers to the sample with RAP containing 12% emulsion, 8% water and 1% mineral filler.

Table 3-4 Comparison of Results to Specifications for Microsurfacing Mix: ODOT (virgin aggregate), LA County (RAP), and ISSA A143 (virgin) (*after* ODOT, 2019; Duncan et al., 2020; and ISSA 2010)

ISSA Test	Description	ODOT Specification (virgin)	LA County (RAP) Specification	ISSA A143 Guideline (virgin)	Results from lab testing		
					Virgin	RAP (A)	RAP (B)
TB-100	Wet track abrasion loss:						
	1-hour soak	450 g/m^2, max.	646.0 g/m^2, max	538 g/m^2, max.	123.53	938.80	109.39
	6-day soak	650 g/m^2, max.	810.0 g/m^2, max	807 g/m^2, max.	712.61	750.12	252.50
TB-106	Slurry seal consistency	N/A	30 mm max.	N/A	29.5	27.5	32.0
TB-109	Excess asphalt by LWT sand adhesion	538 g/m^2, max.	N/A	538 g/m^2, max.	522	603	544
TB-113	Mix time @ 25 °C	Controllable to 120 seconds	N/A	Controllable to 120 seconds, min.	300	156	240
	Mix time @ 40 °C	Controllable to 45 seconds	N/A	N/A	50	50	100
	Mix time at maximum expected air temperature during application	N/A	Controllable to 120 seconds, min.	N/A	N/A	N/A	N/A
TB-114	Wet Stripping	N/A	N/A	Pass (90%, min.)	PASS	PASS	PASS
TB-139	Wet Cohesion:						
	30 minutes min. (set time)	12 kg-cm, min.	N/A	12 kg-cm, min.	16	14	16
	60 minutes min. (traffic)	20 kg-cm, min or near spin	N/A	20 kg-cm, min or near spin	20	18	19
TB-144	Saturated Abrasion Compatibility	2 g loss, max.	N/A	N/A	1.02	N/A	0.46
	Classification compatibility	N/A	N/A	11 Grade Points	3	N/A	4
TB-147	Lateral displacement	5% max. (for leveling and rut fill courses only)	N/A	5% max.	1.36%	2.66%	1.13%
	Specific gravity after 1,000 cycles of 125lb (56.71 kg)	N/A	N/A	2.10 max.	N/A	N/A	N/A

Based on the comparison of the results presented above, the recommended mix designs are presented in Table 3-5.

Table 3-5 Final mix design recommendation

Aggregate type	Emulsion content	Water content	Cement content
Virgin	12%	8%	1%
RAP	12%	8%	1%

Mix design results for the virgin aggregate mix were within requirements for ISSA, LA County and ODOT standards for mix time and cohesion and met the requirements for wet track abrasion and loaded wheel testing. For mixes with RAP, the mix design with 10% asphalt emulsion fell short of the requirements for 1 hour cohesion, the 1-hour soak weight loss for wet track abrasion and lateral displacement, hence was not chosen for the final mix design. The RAP mix with 12% emulsion meets all the specifications due to a higher asphalt content.

Despite having residual asphalt, the binder coating on the RAP samples may reduce cohesion and bond strength with the asphalt emulsion residue, hence a higher dosage is needed to satisfy the identified specifications. A longer curing time seems to remedy this condition, as seen in the 6-day soak test for the wet track abrasion; however, the failure to meet initial 1 hour soak time aggregate loss requirements does not permit the use of the RAP with 10% emulsion mix if a fast opening time to traffic is targeted. The cohesion test results further highlight the need for longer curing times for samples with RAP, since none of the RAP mixes met specifications for the 60-minute cohesive strength requirement of 20Kg-cm, once again potentially pointing to the existing binder that coats the RAP particles that inhibits early strength formation. A higher asphalt content in the mix design of RAP samples may remedy this but runs the risk of high sand adhesion values. Also of note are the results for the Schulze-Breuer and Ruck test (ISSA TB 144) in which the RAP samples had much lower abrasion loss and greater percent coating than the virgin samples, indicating the potential benefit in terms of durability for the RAP microsurfacing mixes.

4 Conclusions and Recommendations

Based on the findings in this study, the following conclusions can be drawn:

- When properly managed and fractionated, 100% RAP is a suitable alternative to virgin aggregate in chip seal and microsurfacing mixes.
- If properly designed and constructed, RAP chip seals and RAP microsurfacing treatments can provide performance consistent with or better than conventional chip seals and microsurfacing treatments placed with virgin aggregate.
- An adequate amount of RAP exists in the state to support the use of RAP as an alternative to virgin aggregate in chip seals and microsurfacing at the local level. Further, four of the six agencies which provided a cost for purchasing RAP indicated the price was $12 or less, therefore, purchasing RAP may be an economical alternative to using virgin aggregate.
- An assessment should be conducted on an agency-to-agency basis to compare the amount of RAP that can be generated or purchased relative to the amount of chip seal and/or microsurfacing placed to determine if it is feasible, and if it is economical to do so.
    - Based on the assumptions considered, including assumed costs to haul and process RAP, if RAP could be purchased for $11.80/ton or less, the overall cost associated with using RAP as an alternative to virgin aggregate in chip seal and microsurfacing would be equivalent or less than the cost of using virgin aggregate. The majority of agencies that provided a cost for purchasing RAP indicated the price was $12 or less per ton, indicating

    purchasing and processing RAP is a feasible and cost-effective alternative to virgin aggregate in chip seal and microsurfacing treatments.
    - Retaining millings from a project is the preferred cost alternative based on the assumptions considered. In doing so, the overall combined cost of chip seal and microsurfacing placement may be reduced by over 50% relative to the costs associated with placing these treatments with virgin aggregate.
    - As current sources of aggregate are depleted, the cost and time required to open new quarries will result in an increase in the cost of virgin aggregate, making the recycling option more economical.
- Additional processing, beyond that completed for use in asphalt concrete, is required for the use of RAP in chip seal or microsurfacing treatments. Costs for processing RAP by contract was included in the cost analyses and were based on costs provided by a RAP processing contractor who serves areas in Ohio. While additional processing is required the cost analyses indicated as long as RAP was retained by the agency or purchased for $11.80/ton, the total cost for chip seal or microsurfacing was equivalent or less than those treatments placed with virgin aggregate.
    - Literature and interviews of practitioners revealed 100% of the RAP pile can be utilized through processing (screening and crushing/grinding) in which 40% of the pile is typically coarse and appropriate for chip seal, and the remaining material is fine and appropriate for microsurfacing.
- Although utilizing RAP for both RAP chip seal and RAP microsurfacing was identified as the most cost-effective use, when only one treatment is selected, the remaining material has value and can be used in other applications. As reported in the literature, when RAP is used for chip seal alone, the remaining RAP material may be used in cold central-plant recycling, stabilized shoulder material, or pipe-bedding material.
- All RAP requirements in LA County specifications for RAP chip seal and requirements of PennDOT RAP chip seal gradation were met with Wayne County RAP. Likewise, all RAP requirements listed in the LA County specification for microsurfacing were met using Lancaster RAP, with the exception of the sodium soundness test, which was not conducted for this study, and slurry seal consistency. Furthermore, where ISSA or ODOT requirements exist for virgin aggregate for the same tests listed in Table 3-2, the tested RAP met or exceeded such requirements. Thus, the use of RAP in chip seal or microsurfacing applications should be feasible. The RAP sources tested herein may be used to develop chip seal and microsurfacing mix designs.
- Based on the laboratory investigation for microsurfacing mixes, it can be concluded mix designs can be feasibly developed utilizing 100% RAP in microsurfacing mixes.
- Laboratory mix designs of RAP microsurfacing and virgin microsurfacing mixes suggest RAP is a feasible alternative to virgin aggregate. In comparing the results for virgin and RAP samples, the RAP samples outperformed the virgin samples for all 3 parameters: abrasion loss; integrity, % retained; and adhesion, % coated. This indicates a possible benefit in terms of durability of using RAP as a replacement for virgin aggregate in microsurfacing mixes.

The following recommendations are made based on the findings of the study:

- Where determined to be economically feasible, 100% RAP be used as aggregate for chip seal and/or microsurfacing.
- To validate the concept, a field study, should be conducted to demonstrate constructability and evaluate the short and long-term performance and cost-benefits associated with using RAP as an alternative to virgin aggregate in chip seal and microsurfacing treatments on local roadways.

  - It is recommended the procedures used for determining the starting aggregate and binder application rates used as part of this study, be considered for use in construction of RAP chip seals . Adjustments to chip seal application rates based on field conditions and results of a test strip may be necessary and should be considered.
  - It is recommended the procedures used for determining the mix components for RAP and microsurfacing mixes used in this study be considered for use in construction of the RAP microsurfacing mixes.
- During the construction of RAP microsurfacing treatments, it is recommended a pneumatic tire roller be used to bond the coated particles and asphalt emulsion. It is recommended the procedures established by LA County (Duncan et al., 2020) be followed such that rolling should begin after the initial emulsion set and prior to reopening the lane for traffic. For microsurfacing this typically occurs within a one-hour timeframe prior to reopening to traffic.

5 Literature Review and Interviews with Practitioners

Five pavement preservation treatments were identified in the literature as having been constructed with RAP as an alternative to virgin aggregate or having the potential to utilize RAP. Those treatments include chip seal, scrub seal, Otta sea, slurry seals, and microsurfacing.

The ODOT Pavement Preventive Maintenance Program Guidelines defines chip seals as "…sprayed application of… asphalt binder covered immediately by a washed… aggregate, and rolled with a pneumatic roller" (ODOT, 2001). Several procedures exist for determining the proportion of materials in chip seals. Commonly used procedures include the Kearby Method, the method currently used by the New Zealand transportation authority and the McLeod method, which is used by most state highway agencies in the United States. These procedures are described in detail by the proposing researchers in Green et al. (2018). Recommended performance guidelines for chip seal are described in ISSA A165.

Scrub seals are not a commonly used pavement preservation tool in Ohio, however they are closely related to chip seals. The Foundation for Pavement Preservation (FP2) describes a scrub seal as a crack filling, sealing and rejuvenating seal accomplished by spraying and then sweeping (or scrubbing) an asphalt emulsion into the pavement surface, followed by the application of aggregate that is rolled into the surface (FP2, 2013).

Another pavement preservation treatment closely related to chip seal is the Otta seal. The Otta seal is a bituminous seal which uses graded aggregates placed on a thick film of soft asphalt (Øverby, 1999). The wide grading envelope associated with Otta seals allow for the use of crushed aggregate, uncrushed aggregate, or the combination of the two (Øverby, 1999), as such, Otta seals may be well suited for using RAP chips.

The ODOT Pavement Preventive Maintenance Program Guidelines defines microsurfacing as "… a thin surface, cold applied paving mixture composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and other additives" (ODOT, 2001). The mix design procedure is described in ASTM Standard D 6372 and performance guidelines described in ISSA A143.

Although slurry seals are not part of ODOT's preventive maintenance program and have seen limited application on local roadways in Ohio, LA County, California has had success with RAP in slurry seal applications (Updyke and Ruh, 2016). A slurry seal is similar to microsurfacing with the most notable differences being in the aggregate gradation and asphalt emulsion type. FP2 (2012) describes slurry seal as a mixture of emulsified asphalt, fine aggregate, mineral filler, water and additives proportioned and mixed on site into a slurry which is spread uniformly onto the pavement surface in a very thin layer. ISSA has recommended performance guidelines for slurry seals described in their A105 publication.

5.1 Field Applications and Performance

Although the literature related to field application and performance of preservation treatments with RAP is somewhat limited, details in this report are gleaned from information obtained from a recent FHWA publication (Duncan et al., 2020) and interviews with practitioners who have experience placing or designing preservation treatments with RAP. Through the literature search a list of agencies which have constructed pavement preservation treatments using RAP were identified and are listed in Table 5-1.

Table 5-1 Agencies/Organizations having experience with pavement preservation treatments containing RAP

Agency/Organizations	Treatments with RAP	Source
Caltrans Maintenance	Chip seal	(Emerson, 2015)
City of Bakersfield, CA	Cape seal	(Hitti, E., 2014)
City of Colton, CA	Slurry seal	(Udelhofen, 2008)
City of Port Hueneme, CA	Microsurfacing	(Metcalf, 2016)
Los Angeles County, CA	Scrub seal, microsurfacing, slurry seal	(LA County Department of Public Works, 2015; Updyke and Ruh, 2016)
Mohave County, AZ	Chip seal	(Emerson et al., 2018)
National Center for Asphalt Technology (NCAT) at Auburn University	Chip seal	(Kessler et al., 2019)
New Mexico Department of Transportation (NMDOT)	Chip seal	(Tarefder and Ahmad, 2018)
Pennsylvania Department of Transportation (PennDOT)	Chip seal	(Jahangirnejad et al., 2019)
San Bernardino County, CA	Chip seal	(Emerson, 2015)

The majority of the agencies listed in Table 5-1 were contacted with a request to complete a questionnaire, presented in Appendix A, or discuss the questionnaire over a phone interview. In addition to agencies, contractors and material suppliers which were reported to have worked with RAP for application to pavement preservation treatments were also contacted. Additionally, two researchers, one from NCAT, and the principal investigator of the recently completed FHWA project titled, "Using Reclaimed Asphalt Pavement in Pavement-Preservation Treatments" (Duncan et al., 2020) were contacted. Those who responded to the research team's request and the type of communication are listed in Table 5-2.

Table 5-2 Practitioners Interviewed or Responded to Questionnaire

Interviewee	Affiliation	Type
Mike Hemsley	Paragon Technical Services, Inc (PTSi)	Questionnaire and follow-up phone interview
Buzz Powell	NCAT	Phone interview
Don Matthews and Doug Ford	Pavement Recycling Systems, Inc. (PRS) and Pavement Coatings Co.	Phone interview
Virgil Valdez and Lisa Boyd Vega	New Mexico DOT (NMDOT)	Questionnaire and follow-up emails
Greg Duncan	Applied Pavement Technology (APTech)	Phone interview
Neal Fannin	Pennsylvania DOT (PennDOT)	Phone interview
Medhat Matta	San Bernadino County, CA	Questionnaire and follow-up emails
Van Truong	Los Angeles (LA) County, CA	Questionnaire and follow-up emails

Results from the questionnaire/phone interviews along with findings from pertinent literature related to field application and performance are summarized for the various pavement preservation treatments constructed with RAP in the following subsections.

5.1.1 Otta Seal

Any studies or agencies incorporating the use of RAP in Otta seals could not be identified through the literature search. However, economic analyses using Minnesota and Iowa as case study locations indicate Otta seals could be more cost-effective than chip seals (Ceylan et al., 2018) because it can be constructed using more economical, local aggregates and utilizing regularly available equipment (asphalt distributor, aggregate spreader, pneumatic-tired roller, and mechanical broom) that is often used for asphalt maintenance (Øverby, 2018). Therefore, Ceylan et al. (2018) recommended future research study on the use of RAP in Otta seals.

As part of the questionnaire sent to practitioners across the country, respondents were asked if they had any experience designing or construction Otta seal with RAP. None of the twelve responding agencies or companies had experience using RAP with Otta seal.

5.1.2 Chip and Scrub Seals

In the western parts of the U.S., the use of RAP in chip seals has been reported in Bakersfield, CA (Hitti, 2014); San Bernardino County, CA (Emerson, 2015), Mohave County, Arizona (Emerson et al., 2018); by CalTrans maintenance division (Emerson, 2015), and by NMDOT (Tarefder and Ahmad, 2018).

Updyke and Ruh (2016) mentioned RAP chips have been used on Avenue J of LA County, California dating back to 2008 in which a half-mile section of scrub seal using RAP was placed. According to Updyke and Ruh (2016), LA County has since placed several chip seal and scrub seals using RAP chips and polymer modified rejuvenating emulsion and reported good performance.

Using specifications from LA County Department of Public Works as a basis for developing their designs, PennDOT began using RAP successfully as coarse aggregate for chip seals (Jahangirnedjad et al. 2019). The RAP was processed to a #8 size. PennDOT reported a savings of $15.00 per ton (a cost savings of about 35%) compared to the cost of virgin aggregate (Jahangirnedjad et al. 2019). Jahangirnedjad et al. found the performance to date of chip seals constructed with RAP was similar to chip seals placed with virgin aggregate. A report on RAP optimization in Pennsylvania (Gibson-Thomas Engineering, 2018) mentioned PennDOT's Districts 1-0, 11-0, and 12-0 use RAP as seal coat aggregate. District 1-0 had been using #8 sized RAP as seal coat aggregate for about five years at the time of the report, and it was seeking to comply with Section 703 of PennDOT's Publication 408 for seal coat aggregates. The section 703 includes a discussion of fine and coarse aggregates and their grading and quality requirements such as strength ratio, soundness, fineness modulus, abrasion, absorption, thin and elongated pieces, compact bulk density, etc.

A hot applied chip seal using RAP was also placed in Bakersfield, California in 2013, using a PG 76-22 tire rubber and 3/8-in. RAP chips (Hitti, 2014). During the design phase, comparisons were made between chip seals with RAP and virgin aggregate, and emulsion and hot-applied binder. Additionally, the use of preheated versus non-preheated aggregate was investigated. It was concluded the non-preheated RAP chip performed as well as virgin aggregate. The hot-applied RAP chip seal was then capped with a Type II RAP slurry seal forming a cape seal. Hitti (2014) reported after one year of traffic the cape seal was performing well with no signs of distress reflecting or aggregate loss.

Updyke and Ruh (2016) also reported a chip seal composed of hot-applied PG 76-22 tire rubber modified paving asphalt and RAP chips was placed in the Lake Los Angeles area in 2013 to determine if non-preheated RAP chips would impact adhesion between chips and binder. RAP chips of 3/8-in. minus size were placed on a two-mile segment of Avenue K, and 5/16-in. minus RAP chips were placed on a two-mile segment of Avenue M. The only problem Updyke and Ruh (2016) reportedly encountered during the first day of placement on Avenue M was traced to moisture content and cleanliness.

Tarefder and Ahmad (2018) conducted a survey of three NMDOT districts each of which constructed chip seals with RAP and chip seals with virgin aggregate with the intent of evaluating cost-effectiveness of chip seal with millings relative to chip seal using virgin aggregate. Regarding the processing of RAP for use in chip seal, the researchers indicated pavement millings are screened using a portable processing plant using two screens, typically 3/8 in. and 1/2 in., to achieve single sized RAP chips. As a result, RAP chips are greater than 3/8 in. and less than 1/2 in. in size. Particles retained on the top screen (1/2 in.) are crushed and rescreened, while those that pass the 3/8-in. screen are placed in a stockpile and considered waste or unusable material. However, it was reported to Duncan et al. (2020) that NMDOT utilizes RAP that is too fine for chip seal gradations in cold central-plant recycling, stabilized shoulder maintenance and pipe-bedding material. RAP particles which pass the 1/2-in. screen and are retained on the 3/8-in. are used for chip seal (Tarefder and Ahmad, 2018). It was reported (Duncan et al., 2020) NMDOT uses as much as 50 percent of the RAP stockpile in coarse RAP chip seal.

Additional costs are associated with RAP chip seal due to the cost to fractionate and haul to the site. However, comparing costs per ton of RAP and virgin aggregate, it was reported (Duncan et al., 2020) that by processing and delivering the RAP to district-wide stockpiles, NMDOT saved more than 40%, such that the total price of RAP chip seal was estimated at $23.50/ton and virgin chip seal was estimated at $40.21/ton.

Present serviceability index (PSI) was computed prior to and after construction of chip seals with and without RAP. PSI at the end of the service life was also estimated (Tarefder and Ahmad, 2018). The authors noted the initial and terminal PSI for chip seals constructed with RAP were greater than those constructed with virgin aggregate. One chip seal constructed with RAP was monitored for one year after construction. Tarefder and Ahmad (2018)reported after one year of service the chip seal constructed with RAP had almost no distress on the surface except for a few loose and broken aggregates. Furthermore, they reported surface appeared dark in color, an indicator of less oxidation. Benefit-cost was evaluated using a cost-effectiveness index (EI) based on the PSI over the service life of the chip seals and the equivalent annual uniform cost. Tarefder and Ahmad stated chip seal constructed with RAP have higher EI compared to chip seal with virgin aggregates in view of lifetime performance. They also reported chip seal constructed with RAP is 23% to 37% more cost-effective than chip seal with virgin chips.

In the recently published report for the FHWA study on Using RAP in Pavement Preservation Treatments, Duncan et al. (2020), present case studies from 6 agencies and service providers:

- LA County, California
- San Bernardino County, California
- NMDOT
- An unnamed private testing laboratory (PTL)
- An unnamed university research center (URC) which is believed to be the NCAT Test Track
- A private preservation treatment applicator (PPTA)

The pertinent information related to chip seal and scrub seals reported by Duncan et al. (2020) for the 6 case studies presented in their report are summarized in the table below.

Table 5-3 Summary of Key Findings for RAP Chip Seals and RAP Scrub Seals from Case Studies Presented in FHWA Study on RAP in Preservation Treatments (*after* Duncan et al., 2020)

Agency/Service Provider	Key Findings
LA County, CA	Specifications: • Their job-order-contract (JOC) permits replacing virgin aggregate with RAP screenings in their chip seals and scrub seals which meet a minimum sand equivalent value of 80 following California Test 217 and meet grading requirements in Table 200-1.2.2.1 of the SSPWC. Other tests required for virgin aggregate are waived. • The minimum sand equivalent value is the same as for virgin aggregate. • Medium fine gradation (5/16 in. x No. 8) is the most commonly designated size for LA County chip and scrub seals Performance: • Pavement sections were monitored the pavement condition ratings in two neighborhoods which were treated with virgin preservation treatments in 2010 and RAP preservation treatments in 2012. Treatments included micromilling, the application of a 5/16" RAP scrub seal followed by a RAP slurry seal. Performance was evaluated 2 years after construction for each neighborhood. In comparing RAP and non-RAP treatments, it was found performance was nearly equivalent. • In another neighborhood using the same RAP treatments, low-severity block cracking and minor bleeding was observed but were consistent with performance of virgin treatments of the same age. While cracking was reflecting through the scrub seal, it was not attributed to the use of RAP

Agency/Service Provider	Key Findings
San Bernardino County, CA	Construction/contracting: • Specialized county crews place RAP chip seal and obtain emulsion and delivery of RAP to the site through contract • Initially started using RAP as an alternative to virgin aggregate in chip seal projects in 2014 using vendor-supplied RAP on a trial basis • After multiple trial sections which were observed to be consistent with expected performance of virgin chip seal, the county began accepting bids for RAP as an alternative to virgin aggregate. • Trucking and hauling cost contribute significantly in terms of which aggregate (RAP or virgin) is most economical. Specifications: • Chip seal materials are specified following Caltrans Section 37, Seal Coats, and SSPWC • RAP chips must meet the same minimum sand equivalent value of 80 as the virgin aggregate • The county specifies chip aggregate, either RAP chips or virgin chips, be of medium-fine 5/16-in x No. 8 size following SSPWC gradation and delivered to the job • Emulsion rates for RAP chip seal is the same as virgin aggregate. Their most common chip seal specification (5/16-in. aggregate) utilizes 0.32 gal/SY of asphalt emulsion and 19 to 20 lbs/SY of aggregate. • A CQS-1h fog seal is applied after the chip seal at 0.1 gal/SY to minimize chip loss and achieve a uninform black surface QA/QC: • A third party consultant tests the delivered material (virgin aggregate or RAP chips, and asphalt emulsion) to verify they meet specifications. • Tests included compatibility tests, daily gradation tests • The third party serves as an inspector for the county crew and is on-site documenting crew actions, application rates, and material properties. A report is prepared at the end of each project and serves as a QA/QC record for the county Treatment selection: • For pavements with higher extents of block cracking, weathering, and raveling, rejuvenating scrub seals are used in which 5/16-in. sized RAP chips are used. A fog seal is applied a dew days later • Crack sealing is conducted 6 months prior to chip sealing to ensure adequate time for the crack fill to cure. Performance:

Agency/Service Provider	Key Findings
	• Chip loss was reported to be less with RAP chips than virgin aggregate • It was reported the asphalt film on the RAP may enhance bonding and the fine particles may serve as a choke stone resulting in improved texture density and reduction in chip loss • The time between crack sealing and applying RAP chip seal is important. When not given adequate time to cure the crack fill material bled through the chip seal surface, resulted in cupping in areas of poor drainage, and caused edge of the crack to form ridges or depressions. • Significant bleeding in the wheelpath was observed for a double layer RAP chip seal near an intersection, leading county personnel to believe the asphalt content of the RAP may have contributed to bleeding more severe than would have been expected with a double layer virgin chip seal • Generally, RAP scrub seals have been observed to have a smooth surface. It is believed to be due to the 5/16-inch sized RAP which created a more tightly knit mat than larger sized aggregate and to the fines adhering to the RAP. • Reflection of transverse cracks have been observed in RAP scrub seal but are expected to occur in chip seal treatments. Costs: • The cost of RAP chips were 20% to 27% percent less than virgin aggregate.
NMDOT	Costs: • Additional cost associate with RAP chip seal is the cost to fractionate and haul to the site • A price comparison between virgin aggregate and RAP chips showed NMDOT saved over 40% district-wide with total prices of RAP chip seal estimated at $23.50/ton and virgin chip seal estimated at $40.21/ton • Only 50 percent of the RAP stockpile is used in coarse RAP chip seal. The fine portion may be utilized in cold-central plant recycling, for stabilized shoulder material, or as pipe-bedding material. One use that is being considered is in RAP microsurfacing. Construction/contracting: • No modifications to their design and construction process were required when using RAP chips as an alternative to virgin chips. • NMDOT crew supervisors design RAP chip seal binder and aggregate application rates using test strips to calibrate and adjust binder and aggregate application rates.

Agency/Service Provider	Key Findings
	• Generally a slight reduction in binder application rate for RAP chip seals, but is dependent on the condition of the pavement prior to the placement. Pavement surfaces with extensive oxidation or weathering necessitate a higher binder application rate. • Fraction and delivery of RAP chip is similar to that of virgin aggregate QA/QC: • Inspectors perform washed gradations on delivered RAP and virgin aggregate to verify gradations meet specification Performance: • Surface texture and bond of RAP chip seals was found to be comparable to that of virgin chip seals. • Bleeding in RAP chip seals was observed to be similar to virgin chip seals and is due to over application of binder material. • Fine conglomerate on the RAP chip particles may elongate resistance to weathering. • RAP chip seal retain a black color longer than virgin chip seals which helps to provide contrast to the pavement markings • Due to the nature of RAP, the particles are coated in aged binder which may improve resistance to oxidation, improve bond, and reduce chip loss.
PTL	RAP processing: • RAP must be fractionated and graded prior to use in any preservation treatment, including chip seal • Fractionation has limited effect on gradation; crushing reduces aggregate size • Aggregate gradation requirements are considered guidelines rather than specifications Specifications: • Most agencies relied on contractors proposing RAP alternatives to virgin aggregate rather than specifications for RAP. Additionally they typically used existing specifications for virgin aggregate with the addition of controls for RAP Mix design: • Compatibility testing still required, but no differences in binder properties for RAP chip from virgin aggregate • Followed ASTM D5360 method for design • Determination of chip loss from the sweep test (ASTM D7000) for a RAP chip seal showed comparable results to a virgin chip seal
URC	Performance:

Agency/Service Provider	Key Findings
	• Two test sections were constructed, a RAP chip seal using a binder with crumb rubber modifier, and a precoated virgin chip seal also using a binder with crumb rubber modifier • Performance characterized by crack maps, surface texture and periodic skid testing. • After 2.5 years of service weathering and raveling were minimal (as expected) in both chip seals, as well as minor low-severity cracking which was assumed to be reflective cracking. • Small aggregate particles were visible in RAP chip seal and no significant chip loss was observed. The precoated virgin chip seal did experience chip loss • The skid number was lower (had less frictional resistance) by the end of the 2.5 year period than the precoated virgin chip seal. • Surface texture was similar between the two sections • Some delamination and potholing occurred in the precoated virgin chip seal, while the RAP chip seal showed none.
PPTA	RAP Processing: • RAP must be fractionated prior to use in preservation treatments • RAP is crushed and screened and separated into chip seal RAP and fines that can be used in slurry seal or microsurfacing. RAP chips typically represent 40% of the total and the remaining 60% can be used for slurry seal or microsurfacing. • Some fractionated RAP clump together and require rescreening, this is generally the case with RAP fines which have more asphalt binder than the RAP chip particles. • Treatments with RAP should be placed at temperatures between 60F and 105F to prevent the RAP from becoming tacky and clogging laydown equipment. Specifications: • Specifications for virgin aggregate for chip seal can be used with slight modifications • Due to the increased coating of fines and asphalt on RAP it typically fails sand equivalency requirements for virgin aggregate. However, the “fines are bound in the asphalt coating” and therefore a lower sand equivalent value will not reduce performance. As such they recommend adjust the sand equivalent or cleanliness specifications for RAP • Typical application rate for RAP chip seals are 28 to 30 ln/SY Performance: • RAP chip seals performed similar to virgin chip seals in test sections, but had better chip retention than virgin chip seals. • Excessive bleeding was observed in double RAP chip seals and is attributed to the asphalt coating on the RAP particles. They

Agency/Service Provider	Key Findings
	recommend placing one layer of RAP chips and one layer of virgin aggregate chip seal • Asphalt coating on RAP chip seals enhance adhesion to the ships and applied binder Costs: • There has been a greater demand for coarse chip (for chip seal) than the fine fraction resulting in an imbalance in material supply, leaving them with surpluses of fine RAP (for slurry seal and micosurfacing). As a result the value of RAP chips has increased compared to the RAP fines.

Regarding chip seals and scrub seals containing RAP, some main points from the questionnaire/phone interviews conducted for this study are summarized below:

Table 5-4 Findings of this project's survey regarding using RAP in chip and scrub seals

Interviewee (company/agency)	Corresponding Comments
Buzz Powell (NCAT)	NCAT placed chip seal as part of the 2015 NCAT Test Track using fractionated RAP and hot applied rubber asphalt binder. Mix design/application rates: • The binder rate was based on experience, not mix design. Construction: • They had an initial problem with the spreader as the RAP was plugging the spreader, it was believe this was due to high heat and humidity which caused the RAP to stick together. Had binder already been applied to the road, this would have been an issue. Performance: • The performance of the RAP chip seal as a surface was not as hoped, however it is believed to have been related to the selection of materials. The project was aimed at utilizing a specific rubber asphalt that differed from tradtional rubber modified binders. It is believed the asphalt and rubber may have separated leading to raveling.
Don Matthews and /Doug Ford (PRS) and (Pavement Coatings Co.)	Mix design/application rates: • The parent rock of the RAP is impoprtant, if the aggregate is soft, the shot rate should be reduced. Performance: • RAP chip seal has excellent adhesion to the road. Once under traffic, "it looks like an open hot mix asphalt."
Lisa Boyd Vega (NMDOT)	Construction: • During placement of the chip seal, the crews noticed less chip loss. Performance: • The RAP chip seals perform pretty much the same as virgin chip seals.

Interviewee (company/agency)	Corresponding Comments
Mike Hemsley (PTSi)	Mix Design: • There is no real difference in application rates but the emulsion formulation may differ slightly to account for less reactive aggregate
Greg Duncan (APTech)	Mix Design: • Using RAP in chip seals works if it is sized and fractionated. It acts as if it was a pre-coated chip. Perfomance: • Polish tendency in RAP may transition to chip seal as NCAT had a skid number issue regarding this, but NMDOT had good results. NCAT's test sections with RAP as hot applied chip seals found a lower friction number in comparison to the pre-coated virgin chip seal section Use of RAP in chip seals resulted in better aggregate bond, blacker texture over a longer period of time, and roughly the same application rate.
Neal Fannin (PennDOT)	Mix Design: • Conducted design of chip seals using a modified McLeod method. They do not use flakiness index, but use 50% VMA. A 5:1 flat to elongated ratio is required, although a 3:1 ratio is preferred. • Some crews reduce binder shot rate. Construction: • Construction starts early in the morning. When applying RAP chip seal, make sure the temperature is not above 120 F to avoid pick up by the delivery trucks. • Storing RAP long term or under hot conditions can cause fine RAP material to clump together. • There are ADT limits on RAP chips seal projects only due to concerns about the aggregate. PennDOT has five levels of skid resistance level for their aggregate. One should look at type of aggregate (limestone, high silica, etc.) and British polish wheel tests. One should consider both aggregate source and gradation. • Although seal coat with RAP is like coated aggregate without coating it, it does not act completely like a coated aggregate.
Medhat Matta (San Bernadino County, CA)	Mix Design: • The amount of RAP usage in the chip seal is per sections 37 & 94 of the Caltrans specifications. PMRS-2H and PMRE emulsions with different additives for rejuvenators are used. • RAP chip seal has the same testing procedures yet different aggregate specifications from conventional chip seal. It also needs lower rates due to aggregate coated with previous emulsions Performance: • There was a bleeding issue on the RAP chip seal project in San Bernadino County. Quality Control: • The advantage of using RAP in chip seal is having consistent size aggregate while the disadvantages are additional testing, additional

Interviewee (company/agency)	Corresponding Comments
	pavement test strips, oversight, emulsion rate changes, inspections, and post treatment inspections for bleeding.

5.1.3 Slurry seal and Microsurfacing

Updyke & Ruh (2016) reported RAP slurry is similar in specification requirements to other polymer-modified slurry seals, with minor exceptions: the residual asphalt on the RAP aggregate contributes to the asphalt content, thus the virgin residual asphalt content requirement is lower. Based on the experience of LA County which has placed (and has a written specification for) RAP slurry seal using polymer modified emulsion, Updyke and Ruh concluded, the benefits of RAP are reduced virgin binder content, lower absorption rate, and wet track abrasion test results similar to mixtures without RAP. They reported a pneumatic-tired roller was required after placement of the RAP slurry seal. They also found the use of aluminum sulfate resulted in a much higher loss of aggregate in the wet track abrasion test than RAP slurry seal made with Portland cement additive (Updyke and Ruh, 2016).

Updyke and Ruh (2016) also reported LA County has used RAP in microsurfacing to a lesser extent with positive results. Dietz (2018) presented a microsurfacing in the City of Port Hueneme, CA constructed with RAP aggregate with a proprietary emulsion has performed well.

The pertinent information related to chip seal and scrub seals reported by Duncan et al. (2020) for the 6 case studies presented in their report are summarized in the table below.

Table 5-5 Summary of Key Findings for RAP Slurry Seals and RAP Microsurfacing from Case Studies Presented in FHWA Study on RAP in Preservation Treatments (*after* Duncan et al., 2020)

Agency/Service Provider	Key Findings
LA County, CA	Specifications (slurry seal): • The county has a specification for RAP slurry seals under Section 908 for Polymer Modified Emulsified Asphalt-Reclaimed Asphalt Pavement Aggregate Slurry Seal (PME-RAPAS). • When compared with their specification for virgin slurry seals (SSPWC Section 203-5) both require a polymer-modified cationic quickset emulsion (PM-CQS-1h), and the emulsion content required for virgin slurry seal is significantly higher than the required emulsion content for PME-RAPAS. • The minimum residual asphalt content required for PME-RAPAS can result in greater emulsion content for PME-RAPAS than virgin slurry seal. • Requirements for RAP in slurry seal is stricter than virgin aggregate. Likewise, higher standards are used for PME-RAPAS mixes. • Due to conglomerates of fine particles in the RAP material, two grading bands are included in the PME-RAPAS specification, one for unextracted RAP and one for extracted RAP. Construction (slurry seal):

Agency/Service Provider	Key Findings
	• A continuous flow mixer is required for RAP slurry seals and at least two applicators must be maintained for continuous operation. • Rolling with a pneumatic tire roller is required on PME-RAPAS for a minimum of three passes to seat the mixture and help the emulsion bind to the RAP. Rolling is done approximately 4 hours after application and after the emulsion has broken but before the road is open to traffic. Specifications (microsurfacing): • Two grading bands are used in RAP microsurfacing, one for unextracted RAP and one for extracted RAP. • Residual asphalt content requirements is greater for RAP microsurfacing then virgin microsurfacing. • Requirements for properties of the RAP (Durability, percent wear, soundness, and sand equivalent) are the same as for PME-RAPAS. • Mixture requirements for the RAP microsurfacing are the same as the virgin microsurfacing mix requirements. Performance: • PME-RAPAS has become the most commonly used pavement performance treatment used for residential roadways in LA County. • RAP microsurfacing is typically applied to arterial roadways which have greater traffic volumes than residential roadways. Overall, RAP microsurfacing is placed less often then PME-RAPAS.
PTL	RAP processing: • 100% of virgin aggregate can be replaced with RAP if the RAP is fractionated and graded into coarse particles for chip seal and fine portions for slurry seal or microsurfacing. • The stockpile should be free of metals, fibers, and soils. • The source aggregate of the RAP should meet agency requirements for aggregate properties of the selected preservation treatment. Mix Design: • RAP-emulsion combination for slurry seal and microsurfacing were evaluated using ASTM D3910 mix design specification, as well as the WTAT following ISSA TB100 and LWT following ISSA TB109. • Other testing conducted included the determination of the asphalt content of the RAP, and optimum asphalt emulsion content. • Due to the asphalt coating on the RAP and the fine conglomerates of RAP which have less surface area than virgin aggregate, RAP

Agency/Service Provider	Key Findings
	slurry seals and microsurfacing have lower optimum emulsion content. • Gradation of the extracted RAP aggregate should be conducted as there are significant differences between washed and extracted gradation. • The gradation of the blend and particle shape affect the optimum emulsion content needed to provide coating and workability.
PPTA	RAP Processing: • RAP with a Type I (fine) gradation has a high residual asphalt content which can create issues during material handling and processing. • Processing RAP to a Type III gradation (coarse) is difficult to create consistent gradations and can be costly Specifications: • Emulsion for slurry seal or microsurfacing must have a 3% polymer modification to enhance aggregate retention. RAP slurry seal and microsurfacing mixes use less asphalt emulsion therefore the polymer modifier helps account for time to set. • Extracted asphalt binder with penetration values greater than 30 are considered too soft and the adjustments must be made by the emulsion supplier. • There is a need for frequent QA/QC testing of materials • There is also a need to have good communication between material suppliers, contractor’s laboratory, and construction crews to address changes in material behavior. Construction: • A pneumatic tire roller is required for both slurry seal and microsurfacing as compaction helps bond the coated particles and asphalt emulsion. • Rolling should begin after the initial emulsion set and prior to reopening the lane for traffic. For microsurfacing this is typically within a one hour timeframe prior to reopening to traffic. For slurry seal rolling is typically started 4 hours after application. Performance: • The increased asphalt content of the fine RAP fraction used in slurry seal and microsurfacing provides better resistance to cracking and raveling, a smoother surface and better bond at the longitudinal joints. • Slurry seals and microsurfacing with RAP were found to have performance equivalent to virgin slurry seals and microsurfacing. Costs:

Agency/Service Provider	Key Findings
	• Less emulsion is required for RAP slurry seals and microsurfacing and can result in a cost savings. • A 2 percent reduction in emulsion translates to a approximately a 4% reduction in material costs. • Cost savings related to lower emulsion content may be offset by the need for pneumatic tire rollers and modifying the emulsion for the RAP source.

Regarding slurry seal and microsurfacing containing RAP, some main points from the OU survey are summarized below:

Table 5-6 Findings of this project's survey regarding using RAP in slurry seal and microsurfacing

Interviewee (company/agency)	**Corresponding Comments**
Mike Hemsley (PTSi)	• To reduce cracking in microsurfacing, a scrub seal can be used before applying microsurfacing. This combination will also help use all sizes of fractionated RAP produced and stockpiled. To address the adhesion/ cohesion/bonding issue, tack coat is applied with microsurfacing. • Some cautions in the design process that should be considered is the RAP aspahlt binder and gradation. If it is too soft or there is too much RAP binder there can be a significant impact on performance. Too little asphalt from the emulsion could cause early performance issues like raveling. Gradation of the unextracted RAP and extracted RAP aggregate should be evaluated. • When designing RAP slurry seals or microsurfacing they still try to meet the same standards as virgin aggregate slurry seal or microsurfacing although the RAP asphalt content and gradations may differ slightly. • Typically 100% RAP in the mix, however when issues were encountered with the RAP binder being too fresh (little aging), virgin aggregate is added to the mix to mitigate tenderness issues.
Lisa Boyd Vega (NMDOT)	• Other Districts within NM have tried using RAP for slurry seals with little success. The result was bleeding due to the remaining binder in the RAP.
Greg Duncan (APTech)	• Using RAP in slurry seal and microsurfacing is complicated. Although it results in 1-2% reduction in virgin asphalt emulsion due to reduced surface area, the RAP causes the emulsion to not break as quickly (a slower set). • The asphalt emulsion can be adjusted to overcome the reduction in set time. A 4-hour break time is allowed for slurry seal, but it is recommended to use a roller to seat the RAP. LA County has a good specification which requires roller to seat slurry seal and microsurfacing.

5.2 *QC/QA Testing and Specifications for Pavement Preservation Treatments with RAP*

Regarding QC/QA testing and specifications for surface treatments containing RAP, some main points from the questionnaire/phone interviews are summarized below:

Table 5-7 Findings of this project's survey regarding QC/QA Testing and Specifications for RAP

Interviewee (company/agency)	Corresponding Comment
Don Matthews and Doug Ford (PRS)	• Difference in slurry seal specifications is because of residual asphalt and the residual becomes active in the mix causing a reduction in emulsion by 18% for type II slurry seal.
Lisa Boyd Vega (NMDOT)	• QA/QC samples are collected only during projects that are done to process RAP into chips. Material is not sampled during chip seal production. • The chip seal crew will calibrate before each season regardless of the material used. • They also perform test strips prior to placement of chip seal to determine the emulsion application rate.
Van Truong (LA County, CA)	• The major differences between conventional and RAP surface treatments could be the mix design and materials testing. In the field, RAP aggregates are generally known as "black" rocks and can easily be differentiated during construction and inspection. For instance, during the chip seal and scrub seal process, spread of virgin rocks (i.e. light color) versus RAP aggregate (i.e. uninform black color) can visually be seen during construction.
	• RAP aggregates must conform to Section 203-6.2.5 of the SSPWC which included testing requirements (e.g. sand-equivalent, asphalt binder content, etc.) of the RAP stockpile at a frequency of 1 test per 1000 tons of processed RAP and a minimum of 1 test per stockpile per month. • Aggregate gradation requirements for RAP also differs from conventional aggregates. For instance, PME-RAP slurry seal requires the grading of combined RAP aggregates to conform to the requirements as shown in Table 908-2.2.2 of the Special Provision.
	• For chip seal, scrub seal and microsurfacing, samples of the emulsion oil and the aggregate are collected daily. • For slurry seal, the LA County DPW materials lab also collects at least 2 field samples of the mixed slurry per slurry mixer per day.
	For chip seal and scrub seal, testing requirements are as follows: • Emulsion with Rejuvenating Agent – A Certificate of Compliance must be furnished to the Engineer for review and approval prior to start of construction. For QA/QC purposes, our material lab collects emulsion samples to test for residue recovered by evaporation, sieve, penetration, and viscosity per AASHTO T59 to conform with Section 905-2.1.1 or 906-2.1.1 in the Special Provisions. • RAP Screenings – minimum sand equivalent of 80 per California Test Method 217 and grading of the combined RAP screenings shall conform to the requirements shown in Table 200-1.2.2.2 of the SSPWC for "Medium Fine".

Interviewee (company/agency)	Corresponding Comment
	• For microsurfacing, verification testing is needed to conform Section 302-4.4 except wet track abrasion test results will not be required. The contractor must provide field samples at the time of verification testing for extraction tests (ASTM D6307) to ensure it conforms to specification. Our material lab collects sample and test for residue recovered by evaporation, sieve, penetration, and viscosity per AASHTO T59 for the emulsion then sand equivalent and gradation for the aggregates
	For PME-RAP slurry seal, testing requirements are as followed: • PME Emulsion shall be grade PMCQS-1h conforming to 203-3.4.5 of the SSPWC which our material lab collects field samples to test for residue from evaporation, sieve, penetration, viscosity per AASHTO T59 for the purpose of QA/QC. • RAP Aggregates – minimum sand equivalent of 60 as shown in Table 908-2.2.1 and grading of the combined RAP aggregates shall conform to the requirements shown in Table 908-2.2.2 of the Special Provisions. • Wet Track Abrasion Test – field sampling and testing requirements during construction is shown in Table 908-7 of the Special Provisions. We have in-house technician onsite for the duration of the slurry project to collect 2 field samples of the mixed slurry per slurry mixer per day. Patties are tested daily and results are recorded.
	• LA County's Special Provisions for PME-RAPAS requires RAP conform to 203-6.2.5 and those in Table 908-2.2.1.

5.3 Laboratory Evaluations of Preservation Treatments with RAP

5.3.1 Laboratory Evaluations of Chip Seal with RAP

Quality Engineering Solutions, Inc. (QES) (2018) investigated using RAP as seal coat aggregate based on test data provided by PennDOT from two stockpiles in Districts 1-0 and 2-0. While District 1-0 data included test results from the Central Office laboratory as well as the District's laboratory, District 2-0 data included test results only from the latter office. Data consisted of asphalt content (AC) and gradation of RAP screenings, fine fractionated RAP and RAP meeting AASHTO #8.

In determining the AC of each RAP type, two test methods were used, solvent extraction and ignition method. QES, Inc. (2018) compared the results of the AC and gradation of the extracted aggregate. As shown in table below, the ignition method resulted in higher AC content. Ignition method resulted in higher AC content. However, it was reported based on plots of the gradation there was no major difference between the solvent extraction method and the ignition method for each aggregate type (QES, Inc., 2018).

Table 5-8 compares the asphalt content results of PennDOT Central Office data with those of Districts 1-0 and 2-0. The asphalt content of the RAP screenings and fine RAP were greater than that of the #8 sized RAP.

Table 5-8 Comparison of PennDOT Central Office, District 1-0, and District 2-0 RAP properties (QES, Inc., 2018).

	Average AC (%)				
	Solvent extraction method		Ignition method		
Aggregate type	Central Office	District 2-0	Central Office	District 1-0	District 2-0
RAP screenings	5.8		7.9	7.0	
Fine RAP	6.7		8.5	7.2	
#8 RAP	4.5	4.0	6.3	5.7	5.6

To determine if the different districts could produce similar #8 sized RAP chips from the pavement millings in their district, gradations prior to extraction of the original RAP screenings, fines and #8s were compared between District 1-0 and 2-0. QES, Inc. (2018) reported the original RAP screenings were different between the two districts. They found the fine RAP gradations were similar and the #8 RAP gradations were very close to one another, leading them to conclude the process for producing #8 RAP in each district resulted in consistent gradation results.

Results were then compared with gradations of AASHTO No. 8 and the Green Book Medium and Medium Fine Gradations. Based on those comparisons QES, Inc. (2018) proposed RAP aggregate gradations for seal coats, as shown in Table 5-9.

Table 5-9 Proposed gradation requirements for RAP Seal Coat Aggregates (QES, Inc., 2018)

Sieve Size	% Passing by weight*
1/2"	100
3/8"	85-100
#4	0-30
#8	0-15
#16	0-10
#200	0-1

*Dry gradation, no wash

5.3.2 Laboratory Evaluations of Slurry Seal with RAP

Saghafi et al. (2019) studied the feasibility of incorporating RAP into slurry seal mixtures by conducting wet cohesion and friction tests (sand patch and British pendulum) under wet track abrasion test (WTAT) and loaded wheel test (LWT). Two Type-3 slurry seal mixtures containing cement and hydrated lime as fillers were tested. The first slurry seal mixture was comprised of virgin aggregate and the second used 87.5% RAP with 12.5% of virgin aggregate passing the No. 100 sieve in order to meet the Type 3 slurry seal gradation in ISSA A105. The prepared RAP slurry seal contained about 7.3% aged RAP binder based on the weight of total aggregate in the slurry seal.

Saghafi et al. (2019) explained adding cement or hydrated lime generally decreased the set times by 30 minutes but that did not noticeably change the set time for RAP slurry seal mixtures. Although the curing time relative to the virgin aggregates increased by 1 hour for RAP aggregate, the wear value in the WTAT decreased by half. Lateral displacement and the British pendulum test results improved considerably for slurry seals made with RAP aggregates. Based on the results of six tests, namely WTAT, LWT, lateral displacement, cure time, sand patch and British Pendulum plus cost, Saghafi et al. (2019) concluded the RAP slurry seal showed better overall performance. When cost was factored in it was found RAP had a with lower cost, up to 14% based on prices in Iran, than the virgin slurry seal. The cost savings may be attributed to a reduction in required asphalt binder for RAP slurry seal mixture which was 19% less than required for the virgin slurry seal.

Saghafi et al. (2019) reported the sand patch test results on WTAT samples showed the RAP slurry seal had the largest drop in mean texture depth (MTD) after the first stage of wear (1 minute). Saghafi et al. (2019) explained this could be caused by the agglomeration of small RAP particles that reduced the embedment into the mat compared with the virgin one. This suggests that RAP slurry seals should be lightly rolled to improve their friction life. They concluded rolling can improve the integrity of the aggregates and increase the embedment of RAP into the mat and bottom layer which leads to better macrotexture friction.

Saghafi et al. (2019) also reported adding cement to slurry seal mixtures led to aggregate agglomeration and increased the apparent particle size. In these experiments, hydrated lime reduced the set and cure time. RAP slurry seal had a lower cure time than the corresponding virgin slurry seal. Although samples containing cement performed better than the other slurry seal mixtures under the LWT, Type 1 cement seemed not to be compatible with the aggregate and emulsion used in this research because it made the mixture more brittle than the other slurry seals. The wear value decreased as the asphalt content increased. Mixtures containing 1% and 2% cement surpassed the maximum wear value limit, while hydrated lime decreased the wear value of the mixes. That sand adhesion increased as the asphalt content increased. The lateral displacement increased with increased asphalt content.

5.3.3 Laboratory Evaluations of Microsurfacing with RAP

Robati et al. (2013) studied microsurfacing mixes containing 0%, 50%, and 100% RAP and 0%, 10%, 17%, 25% and 33% recycled asphalt shingles (RAS) using the modified cohesion test (ISSA TB 139), WTAT (ISSA TB 100) and the multilayer LWT (ISSA TB 147, method A). The mix with 100% virgin aggregate, all mixes with RAP, and the RAS mixes with RAS contents of 17% and lower met the ISSA criteria for the modified cohesion test (30 minutes and 60 minutes) and multilayer LWT vertical and lateral displacement. All mixes met the ISSA criteria for WTAT however, the researchers concluded the test method was vague because of no variation in the results. The researchers wrote "…any amount of RAP from 0 to 100 percent can be added to the conventional microsurfacing mixtures prepared using virgin aggregate".

In the same way, Garfa et al. (2016) investigated microsurfacing mixes constructed with 0% and 100% RAP. The evaluation consisted of modified cohesion test (ISSA TB 139), WTAT (ISSA TB 100) and the multilayer loaded wheel test (ISSA TB 147, method A). Three types of emulsified asphalts were utilized with 3 gradations: fine, dense (average), and coarse graded. No effect of granularity on the cohesion test at 30 and 60 minutes was identified. The fine graded RAP mix failed the WTAT. Results were mixed for the horizontal and vertical displacement test. One dense graded and one coarse graded mixture did not pass the test. Garfa et al. (2016) concluded the results of the WTAT and displacement tests showed acceptable behaviors for all blends investigated. However all mixtures had issues with cohesion and were reported to have longer times than the ISSA time specification needed to reach good cohesion.

To improve cohesion, various parameters were evaluated relative to ISSA requirements including granularity of the aggregates (and RAP), the nature of the asphalt emulsion, and the cement content (Garfa et al., 2016). The researchers found cohesion improved after a longer rest period, indicating the time to open microsurfacing mixes constructed with RAP in the field is greater than that of microsurfacing constructed with virgin aggregates. Additionally, Garfa et al. (2016) reported the emulsion selected can influence the behavior of microsurfacing made with RAP and recommended the emulsion be adapted to the RAP being used due to the interactions between aged asphalt binder and the asphalt emulsion.

Another laboratory study in which RAP was used in microsurfacing, at 100%, 69% and 43% RAP contents, was performed by Poursoltani and Hesami (2018). While all the mixes met the criteria in the ISSA guideline for microsurfacing (ISSA A143), the microsurfacing mix with 69% RAP outperformed the other two in most microsurfacing mix design tests such as cohesion test, 6-day WTAT, LWT, and wet stripping test as well as optimum bitumen content. The researchers found mixtures containing more RAP would demand lower amounts of additive to increase the mixing time and workability, which could reduce the cost of material preparation. The test showed an increase in the RAP content used in the mix results in an increase in the required water content and a reduction in the additive content required for the mix.

In Poursoltani and Hesami's (2018) work, RAP-containing mixtures demonstrated a better performance in terms of flushing distress and stripping. They concluded, in the wet stripping test, RAP microsurfacing mixtures can solve the problem of aggregate non-coating to a great extent. Also, in the cohesion test, the RAP-containing samples showed a greater ability to maintain aggregate coating. However, mixtures containing RAP showed a weaker performance compared to the mixture containing 100% virgin aggregate (VA) in both cohesion test and WTAT. The adhesion of bitumen emulsion with the aged bitumen spread over the RAP aggregate surface was less than its adhesion to the VA and was aggravated in a wet environment.

Poursoltani and Hesami (2018) asserted RAP-containing mixtures needed about 1% more bitumen than those containing virgin aggregate to obtain sufficient cohesion within the specified short time period, usually within 1 hour the road is open to traffic. This seems to contradict such benefits of RAP as reduced virgin binder content due to residual asphalt content of the RAP aggregate reported by Updyke and Ruh (2016). However, the Poursoltani & Hesami (2018) indicated using more binder is still reasonable because the mixture containing 100% virgin aggregate, in contrast, was more sensitive to the change in bitumen content as more deformation occurred with a small change in the amount of bitumen emulsion used.

More recently, Yang et al. (2019) examined the contribution of RAP binder when mixed with microsurfacing. They explained RAP forms a "black rock" after being blended in the microsurfacing because there is inadequate energy to melt the RAP binder in this cold recycling process. However, the performance of the RAP is influenced as temperature increases or diffusion occurs during the service period of the microsurfacing. Yang et al. (2019) mixed three levels of RAP binder in microsurfacing mixes with RAP contents of 20%, 50%, 80%, and 100%. Then, the researchers compared a simulated specimen, a pseudo RAP specimen, with a specimen in which RAP was mixed with microsurfacing. The investigators concluded "…An analysis of the pseudo RAP specimen suggested that RAP binder contributed 0%–10% of the performance of microsurfacing." Finally, based on the performance tests conducted, it was shown incorporating 100% RAP into the microsurfacing mixture is feasible.

Another recent research study on microsurfacing mixtures with RAP was conducted by Wang et al. (2019) in which performances of microsurfacing mixtures containing RAP were compared with those without RAP. Comparisons were drawn based on four key aspects: (a) mixing condition; (b) moisture susceptibility; (c) resistance to shear; and (d) skid resistance. They proposed a modified method of optimal asphalt content (OAC) determination for RAP microsurfacing mixtures. According to the research, adding RAP could improve the mixing time but there was an optimum RAP content based on the optimized rutting resistance. With the increase of RAP content, the OAC decreased while the moisture and skid resistance of microsurfacing were improved.

In the work by Wang et al. (2019), RAP materials were pre-sieved to remove large size particles greater than 9.5 mm. For the remaining RAP materials binder content and gradation (AASHTO T 164, 2018; and AASHTO T 30, 2015, respectively) were determined. Five mixtures were prepared with the same gradation falling somewhere in the middle of the upper and lower gradation bands of ISSA Type III microsurfacing, yet with different RAP contents of 0%, 20%, 40%, 60%, and 80%. The researchers tried to control RAP variability in the specimen preparation by sieving the RAP materials (0–9.5 mm) further into two fractions: 80% passing the 4.75 mm sieve and 20% retained on the 4.75 mm sieve (and passing the 9.5 mm sieve). The material components of the asphalt emulsion were 63% asphalt, 2% emulsifier, 3.5% latex, and 32% water. Type I Portland cement (target compressive strength 42.5 MPa) was added at 1% by weight of minerals in all microsurfacing mixtures. Also, 8% water content was used in all RAP mixture specimens. Two different emulsified rejuvenators were applied with 45% and 50% residual contents

Wang et al. (2019) found in their study there is a general trend that displacement decreases first and then increases with an increase in asphalt content. After selecting the lower and upper potential asphalt contents (PAC_1 and PAC_2), the researchers determined the potential asphalt content (PAC_3) at the minimum displacement. Wang et al. (2019) reported this validates the hypothesis OAC for rutting resistance may be determined at the minimum vertical and lateral displacements as specified by ISSA TB147. As such, the OAC was obtained after comparing PAC_3 with PAC_1, and PAC_2. In the study, Wang et al. (2019) found OAC decreases with an increase of RAP content. This indicates the usage of RAP could reduce the virgin binder content requirement by contribution of the RAP binder and by limiting binder absorption. Therefore, a benefit of using RAP is saving raw materials and cost.

Wang et al. (2019) hypothesized for high RAP usage not all the RAP binder can be blended into virgin binder. Rather, it behaves as a layer of ''soft" black stone, which becomes weak and susceptible to rutting under loading. Hence, the researchers studied whether the use of rejuvenators might restore the initial characteristics of RAP binder in RAP microsurfacing. Two types of rejuvenators, emulsified Evoflex CA (R1) and emulsified LE (R2), were applied to the mixture having the worst rutting performance, the 40% RAP microsurfacing mixture, at application rates of 4, 6, and 8% by weight of RAP binder. The emulsion contents were selected as 5, 6, and 7%. With the increase of rejuvenator agent (RA) content, rutting resistance increased. It is believed the addition of rejuvenator improved the blending of RAP binder and virgin binder, reduced the ''soft" black stone effect, and resulted in improved rutting resistance. In addition, with one emulsion content, the higher the RA content improved the mixing condition (longer mixing time) of RAP microsurfacing mixture. Wang et al. (2019) concluded it is possible adding the rejuvenators increased the light molecular weight and facilitated rebalancing the chemical composition between the virgin and old binder.

Compaction in the laboratory mix design was proposed by Wang et al. (2019) to improve the rutting resistance and accelerate curing. The researchers compacted the mix manually with a ''U"-shaped steel screed using a sawing action until the vertical displacement was not apparently change. It was observed clear water expelled at the surface of specimen when compacting the specimen, indicating its increased capability of carrying traffic. Wang et al. (2019) test results showed compaction significantly reduces percent vertical displacement (PVD) and percent lateral displacement (PLD).

Wang et al. (2019) suggested compaction be included in the mix design stage for specimen preparation when incorporating RAP in microsurfacing. After using rejuvenators and compaction in the laboratory, the rutting resistance of 40% RAP mixtures, which had the worst rutting performance, was better than 0% RAP mixtures. This indicates both compaction and rejuvenating agent are important strategies for RAP microsurfacing mixtures (Wang et al., 2019).

Wang et al. (2019) showed the aggregate loss generally reduces with the increase in RAP content. The investigators explained "it is possible the hydrophobic property of RAP affects the interaction of the materials system with water. Moisture is harder to infiltrate the RAP-virgin binder interface (cohesion problem), as compared to the binder-aggregate interface (adhesion problem)". Furthermore, while there was no consistent trend in terms of the impact of RAP usage on the shear resistance of the microsurfacing, BPN increased with the increase in RAP content, indicating improved skid resistance. However, Wang et al. (2019) points out the reasons the increased skid resistance of microsurfacing mixes with RAP is still unknown and is worth further investigation.

Wang et al. (2019) also discussed the consequence of adding RAP into microsurfacing on the breaking time of emulsion and the mixing time due to the hydrophobic property of RAP. The researchers found the best mixing condition achieved was for 40% RAP mixtures and then mixing time decreased with RAP content. "The result implicates the adhesion between RAP and emulsion is worse than that between limestone and emulsion as the contact angles of RAP with emulsion are larger. When the RAP content is low, the interaction between limestone and emulsion dominates the mixture system causing the water of mixtures hard to expel in a short time," explained Wang et al. (2019). Wang et al. (2019) stated, "adding RAP reduces the interaction between limestone and emulsion leading to increased mixing time until reaching the best mixing condition. With the further increase of RAP, it substantially decreases the adhesion between limestone and emulsion in the mixtures system, causing the mixing time decreases."

5.3.4 Mix Design: Chip Seal with RAP

For chip seals, there are procedures for determining the proper quantity of asphalt binder and cover aggregate. The most common design methods are Mcleod Design Method, Modified Kearby Method, Ausroads, and Spread Modulus Method. Regardless of the design method chosen, the material properties of the aggregate and asphalt are first evaluated, then calculations and lab testing are performed to determine the required application rates. Adjustments to the application rates must be made to account for traffic volume, absorption of the binder into the existing pavement and cover aggregate, characteristics of the cover aggregate, etc.

Los Angeles County has used 100% RAP in all their scrub seals and slurry seals since 2012 with emulsion that has a polymer and a rejuvenator (QES, Inc., 2018). According to the QES, Inc. (2018) report Los Angeles County utilizes application rates in the range of 0.25 – 0.35 gal/yd^2 from the Greenbook (SSPWC, 2018). Their special provisions identifies the application rate as the average from this range, as 0.30 for chip seals. This indicates there can be field adjustment of the emulsion application rate. The emulsion application rate is adjusted for existing surface conditions. Section 906-2.2.2 of LA County DPW's special provisions discusses a minimum sand equivalence of 80 for RAP material (QES, Inc., 2018).

5.3.5 Mix Design: Microsurfacing and Slurry Seal with RAP

As previously stated, Updyke & Ruh (2016) indicated RAP slurry is similar in specification requirements to other polymer-modified slurry seals, with minor exceptions. The residual asphalt on the RAP aggregate contributes to the asphalt content, thus the virgin residual asphalt content requirement is lower.

Although differences exist between slurry seals and microsurfacing, for the purpose of mix design, the differences in the chemistry of the systems are not relevant (Andrei, 2007). So, a single mix design procedure can be followed for both systems. The main difference is the degree to which each system met the performance requirements in the field. Therefore, the mix design must attempt to identify and quantify performance requirements. (Andrei, 2007)

Recently, Wang et al. (2019) proposed a modification of the mix design for microsurfacing, including the one with RAP, consisting of three aspects: determining OAC by considering rutting performance; using rejuvenators to restore the initial characteristics of RAP binder in microsurfacing, and proposing compaction methods in the specimen preparation. In their modified mix design procedure, the mixing time test following ISSA TB113 is used to verify mixtures compatibility and establishes the proper component proportions. The WTAT test following ISSA TB100 is used to establish the PAC1 to prevent excessive raveling of microsurfacing by one-hour soaking. The LWT following ISSA TB109 is used to establish the PAC2 to avoid severe asphalt flushing of microsurfacing under heavy traffic loads. The same LWT test device is also used to evaluate the rutting resistance of microsurfacing, according to ISSA TB147.

The modification of the mix design proposed by Wang et al., (2019) which are discussed above is also graphically presented in the flowcharts below.

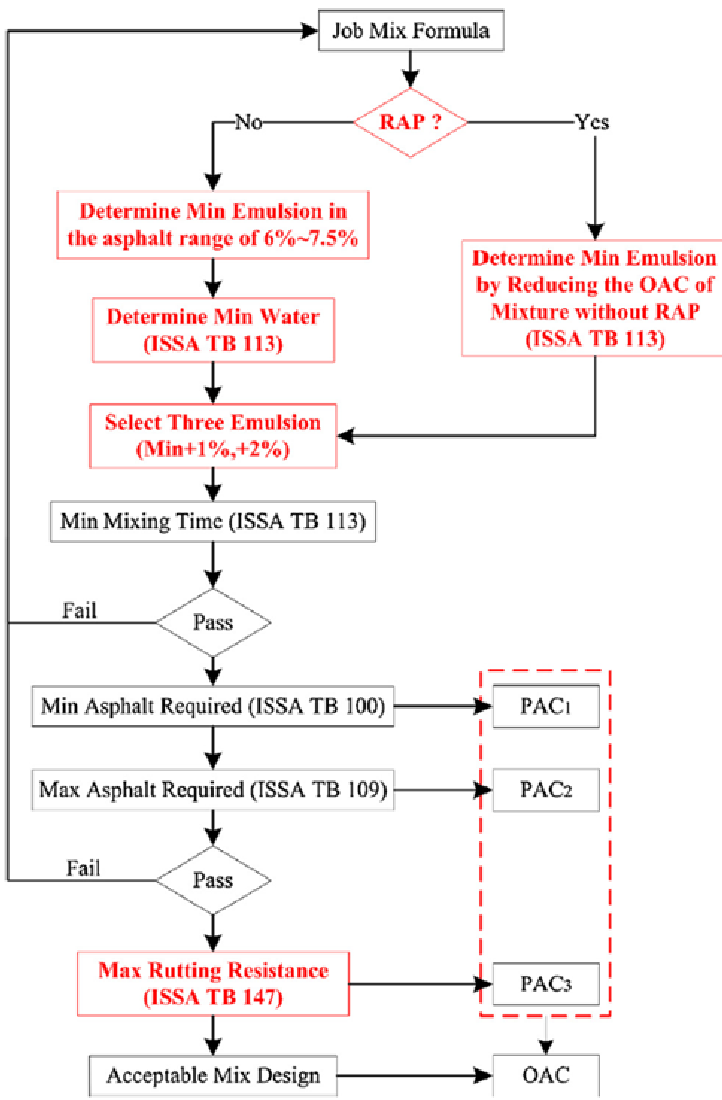


Figure 5-1 Flowchart of ISSA modified mix design procedure for microsurfacing (Wang et al., 2019).

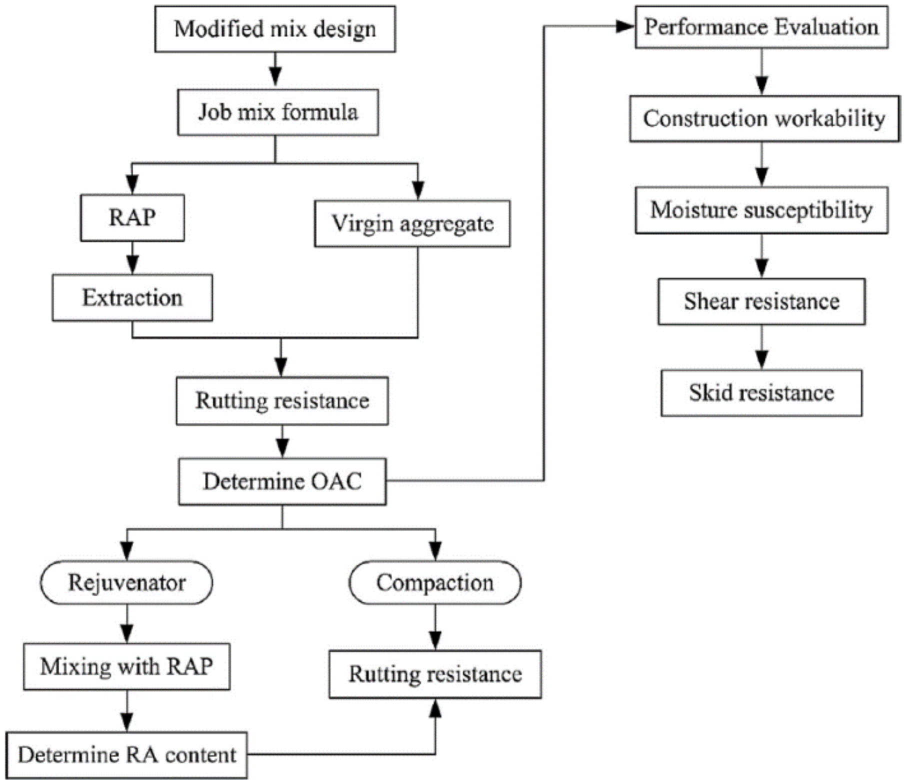


Figure 5-2 A flowchart of the experimental methods for RAP Microsurfacing (Wang et al., 2019).

6 Analysis of RAP Supply/Demand and Potential Cost Savings for RAP in Chip Seal and Microsurfacing Treatments for Local Agencies in Ohio

6.1 Supply vs. Demand of RAP in Ohio

Asphalt producers are one of the best sources of information for understanding the supply of RAP in an area. The National Asphalt Paving Association (NAPA) performs an annual survey to quantify the use of recycled materials. NAPA is currently collecting data for the 2020 survey and this report uses information from the 2019 survey on recycled materials. Another source of information is bid items for milling and overall mix tonnage from contracts awarded by Ohio Department of Transportation (ODOT).

6.1.1 Availability of RAP in Ohio based on NAPA Survey

NAPA's annual survey provides national level information. NAPA's survey shows national trends of RAP use increasing over time. Specifically, in 2009 national RAP use was approximately 15% on average. This national average has increased to approximately 20% RAP in 2014 followed by a plateau at 20% in the following years (Williams et al. 2019).

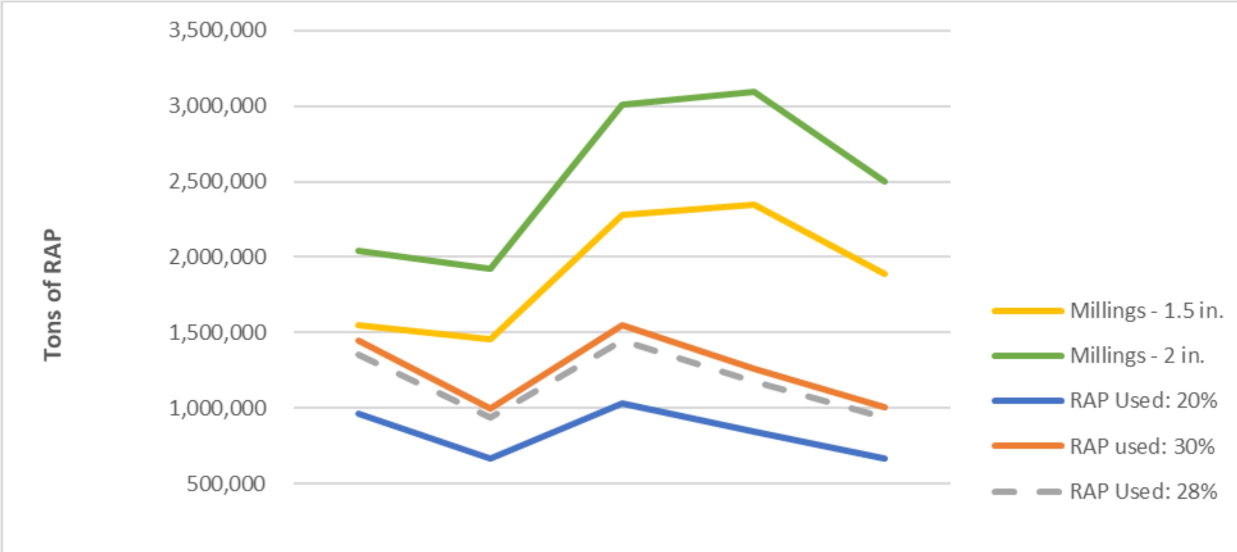
In the 2019 NAPA publication (Williams et al., 2019) (which represents the 2018 construction season), the survey results for the State of Ohio represent nine responding companies who represent 88 production plants across the state. During the 2018 construction season, Ohio producers were estimated to have produced 16.9 million tons of asphalt mixtures and in the survey 12.3 million tons were reported, thus representing 73% of Ohio's HMA/warm-mix asphalt (WMA) production. The 2018 survey showed asphalt mixtures averaging about 20% RAP for Ohio DOT asphalt mixtures and just over 23% RAP for commercial and residential asphalt mixtures. Producers in Ohio report using an average estimated RAP percent of 28% for 2014-2018 except 27% was reported in 2016.

The economic conditions favor RAP use but supply-chain and logistics of RAP handling are an important consideration. The amount of RAP stockpiled is a helpful indicator for RAP availability. In the 2018 NAPA survey, Ohio producers reported 8.15 million tons of stockpiled RAP, an increase compared to the 3.58 million tons reported in 2017. Based on market analysis, NAPA estimates a total of 11.20 million tons of RAP were actually stockpiled Ohio in 2018 (3.05 million tons in addition to reported RAP tonnage stockpiled). Comparing Ohio RAP stockpiles to other states, Ohio has the largest amount of RAP stockpiled.

6.1.2 Availability of RAP based on contracts awarded by ODOT

The supply of RAP is dependent on the number of projects requiring pavement planing, while the primary demand for RAP will be controlled by RAP used in HMA/WMA. Via phone interviews or the completion of the questionnaire via email, asphalt producers interviewed in Ohio indicated the overall percentage of RAP that is retained by the agency (local or state) is small, while ODOT is the largest generator and consumer of RAP. Therefore, estimating the amount of RAP from ODOT bid items from contracts awarded over previous years would be a reasonable estimate of RAP generated in the state.

The amount of RAP generated and used for ODOT projects was estimated based on contract awarded information publicly available on ODOT's website for years 2015-2019. The RAP generated from milling was determined from the square yards of pavement planing of asphalt concrete, ODOT Items 254 and 897 (Class A), which were converted from square yards to tons, assuming an average mill depth of 1.5 (38.1 mm) or 2 inches (50.8 mm) and a factor of 1.95 cubic yards per ton. The amount of HMA/WMA produced for ODOT for these years was determined from the sum of the cubic yards of mix awarded under ODOT Items, 441, 442, 301, 302, and 424. Tonnage was estimated based on a factor of 1.95 tons per cubic yards. Figure 6-1 displays the tons of RAP milling (green line) compared with RAP use if 20% of HMA/WMA production is RAP (blue line), if 30% of HMA/WMA production is RAP (orange line), and if 28% (the average RAP usage identified in the NAPA survey) of HMA/WMA production is RAP. Based on an average RAP usage of 28% in HMA/WMA production, and a conservative mill depth of 1.5 inches (38.1 mm) annual excess RAP ranges from 195,000 tons to nearly 1.2 million tons per year. This comparison illustrates asphalt producers in Ohio will not be able to use all their RAP in HMA/WMA alone under ODOT's current HMA/WMA specifications.



	2015	2016	2017	2018	2019
Millings - 1.5 in.	1,547,210	1,458,877	2,281,859	2,347,088	1,891,741
Millings - 2 in.	2,042,318	1,925,717	3,012,054	3,098,157	2,497,099
RAP Used: 20%	965,556	666,581	1,034,674	841,817	668,987
RAP used: 30%	1,448,334	999,871	1,552,010	1,262,725	1,003,481
RAP Used: 28%	1,351,779	933,213	1,448,543	1,178,544	936,582

Figure 6-1 Availability of RAP versus demand for RAP over time, based on ODOT contracts awarded

6.1.3 Availability of RAP for Ohio's Local Agencies

When RAP is generated by pavement milling for ODOT projects, unless otherwise stated in the plans or contract documents, the RAP is retained by the contractor (most often the asphalt producer). As a result, the largest supplies of RAP are housed at asphalt plants around the state. While asphalt producers may sell excess RAP, it can be costly. As part of phone interviews/questionnaires, three asphalt producers reportedly sold RAP at FOB plant prices ranging from $20/ton to $50/ton. However, the price local agencies reportedly paid when purchasing RAP tended to be lower, with rates ranging from $5/ton to $25/ton.

Furthermore, based on phone interviews or questionnaires completed via email with asphalt producers it was found RAP supplies are concentrated near urban areas where pavement milling is conducted more frequently to restore cross slope, meet elevation requirements (e.g., curb and gutter height), or where large interstates intersect, while there may be little to no RAP located in rural areas. Information provided by the asphalt producers interviewed for this study is summarized in Appendix B, section 13.1. When the cost of RAP is combined with haul costs that have been reported to be prohibitively high, obtaining RAP from urban areas for use in rural areas may not be feasible.

Based on conversations with contractors in western USA, and agencies that have experience using RAP in chip seals, the use of RAP in pavement preservation works best in terms of economics when the RAP is retained by the agencies. Therefore, the research team reached out to local agencies to gather information related to how many local agencies currently retain RAP, and how stockpiled RAP is used. A survey of local agencies was issued through Ohio's Local Technical Assistance Program (LTAP). Additionally, phone interviews were conducted with selected agencies to gather information regarding

RAP storage and usage and information pertaining to aggregates used in pavement preservation treatments. Survey and phone interview questions and responses are presented in Appendix B, sections 13.2.2 and 13.3.1, respectively, as well as a summary of the results of the survey and phone interviews in section 13.2.1. Responses to the survey and phone interview questions pertaining to RAP usage and storage are tabulated in Appendix B, section 13.2.3

Including agencies with which phone interviews were conducted, and those that responded via the online survey (including incomplete surveys), a total of 22 agencies responded with the majority representing counties. Regarding the availability of RAP, six agencies indicated they had purchased RAP in the past, with prices ranging from \$5/ton to \$25/ton. One agency indicated the RAP they purchased was asphalt waste, and was \$10/ton to \$12/ton, they also indicated they would like to purchase RAP (millings) but it is hard to come by.

Another source of RAP for local agencies is that which is generated by pavement millings from their annual paving projects. Participants were asked how much pavement planing in square yards (SY) is conducted each year. The majority (13 agencies) responded pavement planing is conducted, with amounts varying widely. The smallest quantity listed was 1,000 SY, while the largest was 200,000 SY. Seven agencies reported values between 25,000 and 50,000 SY.

As an alternative to purchasing RAP for use in chip seals or microsurfacing, agencies may retain RAP generated from pavement millings. Therefore, agencies were asked to report how much RAP was stockpiled in 2019 and how that RAP is used. Sixty percent (60%) of those responding to the question reported they had stockpiled RAP in 2019, with the amount stockpiled distributed evenly among the 4 ranges from which the agency could choose from, as described below. One agency, the City of Lancaster did not report a range but did report they have a stockpile of approximately 7000 tons that had been accumulated over the last couple of years, and they had been planning to use the RAP for chip seal and microsurfacing treatments. While City of Lancaster can be considered an urban area, many of the agencies that reported some amount of RAP was stockpiled in 2019 are rural counties, including the counties of Ashland, Auglaize, Crawford, Fulton, Huron, Tuscarawas, and Wayne.

- < 500 tons: 2 responses
- 500 – 1000 tons: 3 responses
- 1000 – 1500 tons: 3 responses
- > 1500 tons: 3 responses

For agencies which reported how their RAP was acquired, all but two indicated 100% of the RAP acquired in 2019 came from pavement millings. One agency reported 50% came from pavement millings and 50% from full depth pavement removal. Another agency reported of their RAP acquired in 2019, 20% came from county projects including milling and reconstruction, 40% came from contractors (which was mostly driveways and parking lot replacement), and the remaining 40% came from county projects including road repairs, storm sewer crossing, etc.

The results illustrate local agencies, including rural counties, can generate pavement millings and stockpile them for future use. Fewer agencies reported purchasing RAP than those that reported conducting pavement planing as part of their annual paving program, however, it does illustrate that at least in some parts of Ohio, RAP from asphalt producers is available to local agencies for purchase. While one agency did report they would like to purchase RAP but it is not available in their area, it is difficult to estimate how many agencies across the state cannot obtain RAP from an asphalt producer in their area. Lastly, using aerial satellite images from Google maps, the research team was able to develop a list of counties that may be stockpiling RAP. The list is presented in Table 13-1 in Appendix B. While this list could not be confirmed within the timeframe of this task, it does provide insight into how much RAP may be available to local agencies. Based on the aerial images 39 counties appear to be stockpiling RAP at the time of the image, 18 did not and the remaining 31 counties could not be determined either due to the quality of the image or the use of shelters which could be used to store RAP, and therefore were classified as "maybe."

6.1.4 Potential Demand of RAP: Pavement Preservation Treatments on Local Roadways

For this study, the demand of RAP is looked at in terms of the virgin aggregate used in pavement preservation treatments that can be replaced with RAP. To assess the amount of virgin aggregate used each year for chip seal, microsurfacing, slurry seal or Otta seals, a survey was sent to local agencies through Ohio's LTAP email distribution list, details are provided in Appendix C. Additionally, phone interviews were conducted as described in Appendix B, section 13.2, and with questions listed in Section 13.3. Participants were asked to report information related to the amount of chip seal, microsurfacing, slurry seals or Otta seals placed each year. The survey and phone interviews found 15 local agencies were using chip seals, four of which were also using microsurfacing, two agencies reported none of the listed pavement preservation treatments were being used, and no agencies have placed Otta seals.

The amount of chip seal placed varied widely among the 14 agencies which reported chip seals had been placed in 2019. Agencies reported the amount in units of SY, "miles", lane-miles or tons of virgin aggregate. Where units of miles were provided, lane miles were assumed, and assuming 12-ft lanes, the amount in SY was estimated from the number of lane-miles. Where tons of virgin aggregate were supplied the provided aggregate application rate was used to estimate the amount of chip seal in SY. As such amounts varied greatly with values ranging from 21,120 SY to 844,800 SY, as shown in Figure 6-2. If 10-ft lanes were assumed the amounts varied from 17,600 SY to 704,000 SY.

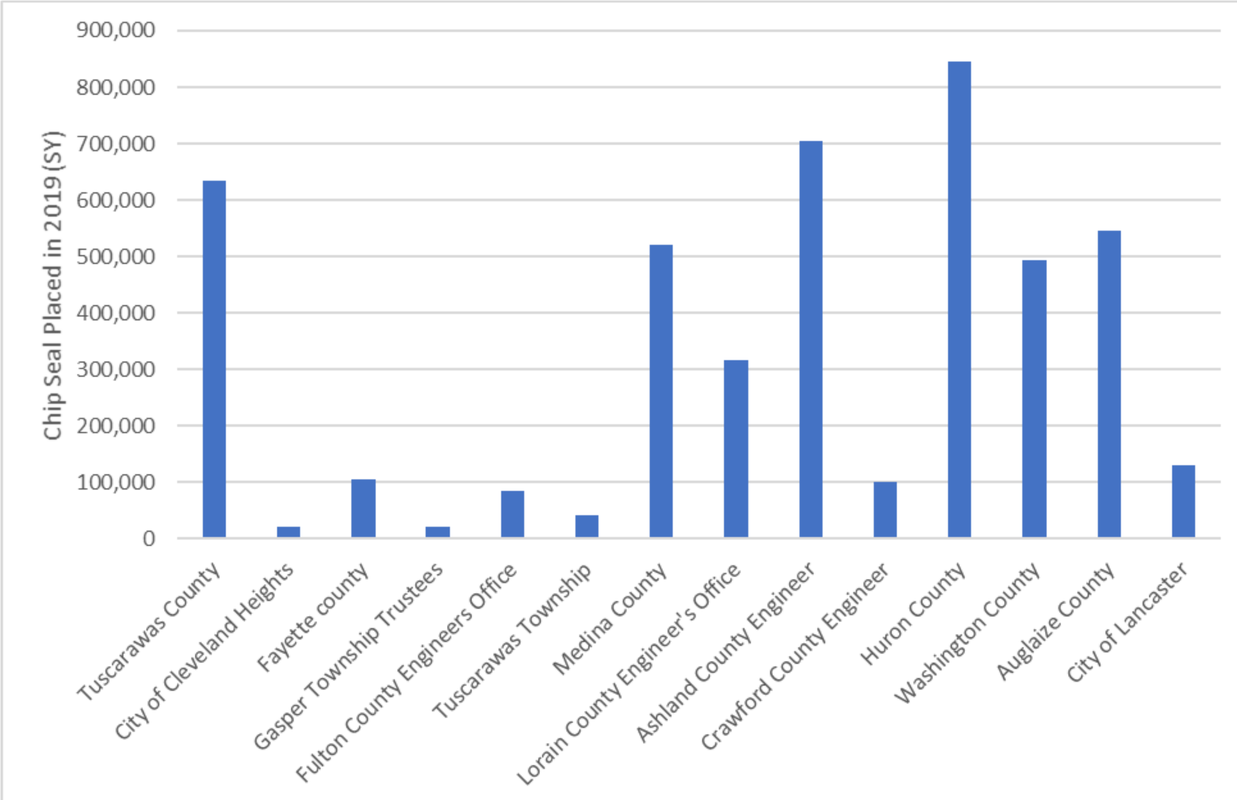


Figure 6-2 Amount of chip seal placed by respondents in 2019

Agencies reported aggregate application rates between 18 lb/SY and 25 lb/SY with higher frequencies (10 of 13 responses) falling between 22 lb/SY and 25 lb/SY. Of the other three responses, two were 20 lb/SY and one was 18-22 lb/SY.

Although four agencies indicated microsurfacing had been placed in their jurisdiction in the last 5 years, only one indicated any had been placed in the year 2019. That agency provided an amount of 60,000 to 70,000 SY at a cost of $2.90/SY to $3.40/SY. They also indicated limestone aggregate was used in their microsurfacing.

6.1.5 Supply versus Demand

To evaluate the amount of RAP that is available and can replace virgin aggregate in chip seal or microsurfacing at the local levels, it is necessary to compare amount of RAP accessible to local agencies to the amount of virgin aggregate used in chip seal or microsurfacing. While RAP may be purchased from asphalt producers, the most economical source of RAP for local agencies may be through the retention of their own pavement millings. It was found through the results of the survey and phone interviews the amount of pavement millings vary widely, although the majority of agencies that responded reported amounts falling between 25,000 and 50,000 square yards (SY) per year. Assuming a mill depth of 1 ½ inches, and a conversion rate of 1.95 CY/ton of RAP, the weight of RAP milled can be estimated for this range, as illustrated below. For pavement planing ranging from 25,000 SY to 50,000 SY, the amount of RAP generated, or the potential supply for this application is 534 tons to 1,068 tons.

RAP generated from 25,000 SY of pavement planing, using 1.5-inch mill depth:

$$25{,}000\ SY \times 1.5\ in \times \frac{1\ ft}{12\ in} \times \frac{1\ yd}{3\ ft} \times \frac{1\ ton}{1.95\ CY} = 534\ tons$$

RAP generated from 50,000 SY of pavement planing, using 1.5-inch mill depth:

$$50{,}000\ SY \times 1.5\ in \times \frac{1\ ft}{12\ in} \times \frac{1\ yd}{3\ ft} \times \frac{1\ ton}{1.95\ CY} = 1{,}068\ tons$$

The results of the second survey and the second series of the phone interviews provided information regarding the amount of chip seal and microsurfacing placed in local agencies around the state as well as aggregate rates used in each application. Due to the limited responses related to microsurfacing, only chip seal will be evaluated here. The amount of chip seal placed in 2019 ranged from 21,120 SY to 844,800 SY when 12-ft lanes were assumed for amounts provided in units of lane-miles. While amounts were lower when 10-ft lanes were assumed, amounts associated with the wider lanes are more conservative and will be used for this analysis. Of the fourteen agencies that provided an amount, five fell in the range of 70 lane-miles to 120 lane-miles, or 434,133 SY to 844,800 SY. The median value of 639,467 SY can serve as the high end of the range of chip seal placed each year for a given agency. The remaining agencies reported between 3 lane-miles and 22 lane-miles (21,120 SY and 130,435 SY) of chip seal were placed in 2019. For this analysis the median value, 75,778 SY can serve as the low end of the range of chip seal placed each year for a given agency.

To determine if the supply is sufficient relative to the demand, the amount of virgin aggregate in lbs needs to be converted to SY of pavement. For this the aggregate application rate for virgin chip seal aggregate in lbs/SY can be used to estimate the amount of virgin aggregate used each year for chip seal. From the phone interviews and survey responses agencies reported aggregate application rates between 18 lb/SY and 25 lb/SY with higher frequencies (10 of 13 responses) falling between 22 lb/SY and 25 lb/SY. If an aggregate application rate of 23 lb/SY were used, the amount of virgin aggregate can be estimated as illustrated below. Based on these assumptions, an agency's required virgin aggregate ranges between 871 tons to 7,354 tons for the year 2019.

For 75,778 SY of chip seal placed the amount of virgin aggregate required is:

$$75{,}778\ SY \times \frac{23\ lbs}{1\ SY} \times \frac{1\ ton}{2000\ lbs} = 871\ tons$$

For 639,767 SY of chip seal placed the amount of virgin aggregate required is:

$$639{,}467\ SY \times \frac{23\ lbs}{1\ SY} \times \frac{1\ ton}{2000\ lbs} = 7{,}354\ tons$$

If 100% of the RAP that is milled can be processed to meet chip seal gradations, then 7% (534 tons RAP/7,354 tons virgin aggregate) to 100% (1,068 tons RAP/871 tons virgin aggregate) of the virgin chip seal aggregate an agency places in one year can be replaced with RAP. While this analysis looks at the ratio of RAP to virgin chip seal aggregate, it is assumed the chip seal would be comprised of 100% RAP or 100% virgin aggregate. Considering the same aggregate application rate was used, this can be translated to percent of SY or lane-miles of virgin chip seal that can be replaced with RAP chip seal. Thus, the range of virgin chip seal an agency can expect to be able replace with RAP chip seal using pavement millings in a given year is between approximately 46,400 SY (1534 tons * 2000 lbs/ton RAP/23 lbs/SY) and 92,900 SY (1,068 tons * 2000 lbs/ton RAP/23 lbs/SY).

This analysis is conceptual, as noted here the amount of chip seal placed in each agency varies widely, as does the amount of pavement millings generated each year. Additionally, it is unlikely 100% of the RAP can be used in chip seal. However, based on discussions with a contractor in Ohio who has processed RAP for chip seal and microsurfacing, nearly 100% of the RAP can be used when processed to achieve both chip seal and microsurfacing or slurry seal gradations. Duncan et al. (2020) reported when fractionated approximately 40% of the RAP stockpile is coarse and is appropriate for chip seal while the remaining fine RAP material is appropriate for microsurfacing. This is also the most economical method for processing RAP for either chip seal or microsurfacing. Therefore, an assessment needs to be conducted on an agency-to-agency basis to compare the amount of RAP that can be generated or purchased relative to the amount of chip seal and microsurfacing placed to determine if it is feasible, and if it is economical to do so.

In conclusion this analysis shows there is sufficient supply of RAP to meet the expected demand for chip sealing and potentially microsurfacing.

6.2 Preliminary Cost Analysis of Using RAP in Chip Seal and Microsurfacing

Recycled asphalt pavement (RAP) is the world's most recycled material by weight. According to NAPA (Williams et al., 2019), 99% of RAP is reused, leading to an estimated savings of $2.9 billion. This section provides a preliminary cost analysis for Ohio agencies interested in using RAP as a substitute for virgin aggregate in chip seals and microsurfacing.

Information for this analysis was obtained from a survey of local agencies and follow-up interviews. In addition, the research team inquired with aggregate suppliers and contractors to present reasonable cost estimates. Costs are variable and can be affected by a variety of factors and each agency should carefully evaluate their own costs and specific project needs relative to availability of materials.

6.2.1 Preliminary Cost Analysis Objectives

This preliminary cost analysis presents important economic considerations for Ohio agencies and practitioners when determining if utilizing RAP in surface treatments makes economic sense. The preliminary analysis investigates associated costs of using RAP compared with virgin aggregates in chip seal and microsurfacing treatments. This section aims to present important considerations for agencies when deciding whether to use RAP. The following sections are included in the preliminary cost analysis:

- Pavement preservation strategies and surface treatment costs based on the survey results and interviews conducted for this project.
- Methods for agencies to obtain RAP for surface treatments.
- Feasibility of processing RAP for surface treatments and associated costs.
- Hauling cost considerations.
- Example 1 analysis: comparing an agency purchasing RAP vs. using virgin aggregate for surface treatments.
- Example 2 analysis: comparing an agency retaining millings from a project vs. using virgin aggregate for surface treatments.

6.2.1.1 Current pavement preservation strategies and associated costs

A survey by the research team asked local agencies in Ohio if they were using chip seal, microsurfacing, and/or Otta seals for pavement preservation. Survey responses and phone interviews include: two cities, twelve counties, and three townships. The survey found 15 local agencies were using chip seals, four of which were also using microsurfacing, two agencies were using no pavement preservation treatments, and no agencies used Otta seals. Results showed chip seals are most often placed by a contractor (7 of 15 respondents), while three respondents placed chip seals using in-house crews, and one agency uses either contractor or in-house crews to place chip seals. Four agencies did not provide a response. Ten respondents noted the amount of chip seals placed in 2019 is about the same as previous years, while two respondents noted a slight increase, and two noted a moderate decrease in the amount placed in 2019 relative to past years.

A few respondents mentioned their chip seal aggregate application rate is approximately 20-25 lbs/sy and the amount of chip seal placed in 2019 is shown in Figure 6-2. The approximate cost of chip seal was $1.07/SY (assuming 12-ft lanes) to $1.20/SY. One respondent noted microsurfacing was approximately $2.90-$3.49/SY. The cost for chip seal aggregate varied. One respondent was as low as $6/ton, three reported values in the $11-15/ton range, two reported values between $18/ton and $20/ton, and three reported values of $22/ton to $25/ton. One agency indicated they use either river gravel at $12/ton to $15/ton or limestone at $22/ton to $24.50/ton. Two respondents noted very high aggregate costs with one $35/ton and another at $80/ton. The research team assumes hauling costs may have contributed to a cost of $80/ton. The most common aggregate size is No. 8 and limestone is the most common aggregate type. A previous research study on chip seal for Ohio's local agencies has also shown crushed river gravel and slag aggregate are also used for chip seal in Ohio (Green et al. 2018). One county provided detailed information for their chip seal program from 2013 to 2019. Their costs are summarized for the year 2019 in Table 6-1 and Figure 6-3 provides their chip seal prices for 2013 to 2019. While 12-ft lanes were assumed in converting lane-miles to SY for Figure 6-2, this county's prices indicate 10-ft wide lanes.

Table 6-1 2019 County Chip Seal Cost Summary

Price	Description
$11,990.40	Material COST / MILE
$1.35	COST / SQ YD
$15,913.04	COST / MILE
$4.21	FINAL chip seal price Per Gallon FOR COUNTY

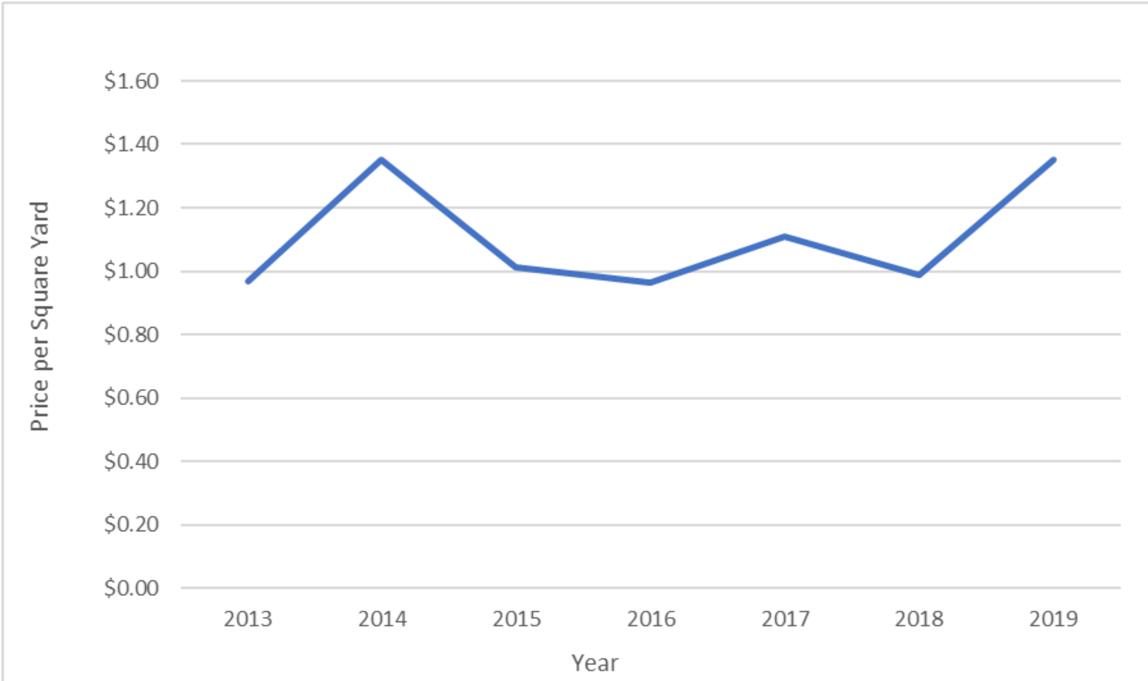


Figure 6-3 County respondent provided chip seal price per square yard over time

6.2.1.2 Methods for Ohio agencies to obtain RAP for surface treatments and aggregate suppliers in Ohio

Agencies in Ohio have two standard options for obtaining RAP: (1) RAP millings can be retained on a project and hauled to the agency's site for use or further processing or (2) RAP can be purchased from a contractor.

Estimated cost for retaining millings from a project is approximately $5/ton based on an estimate from an Ohio county. This cost would depend on project-specific conditions and hauling requirements.

Costs related to purchasing RAP from a contractor was asked in the survey and phone interviews of Ohio local agencies. Of the 22 local agencies that responded to this question, two were cities, 15 were counties, and five were townships. Only six agencies purchased RAP directly. The cost ranged from $5 to $25/ton. From the survey results, a typical value is approximately $20/ton for an agency to purchase RAP from a contractor, which does not cover hauling or additional fractionation costs.

The survey also asked respondents how they currently use RAP. RAP materials have utility as recycled material in asphalt or can be used an aggregate material. Respondents use the RAP for HMA, granular base, fill material, shoulder, berm material, cold central plant recycling, aggregate road surfacing, repairs, widening/cuts, and one respondent was planning to use RAP in a chip seal.

Several agencies mentioned in the survey they stockpile RAP, however, since all counties did not respond to the questionnaire, to better discern how many agencies are likely stockpiling RAP, an informal Google Map aerial survey was performed. The survey investigated whether the county appeared to have stockpiled RAP on-site. The results of this informal aerial survey are shown in Figure 6-4. Counties marked with a "maybe" had a covered area that appeared to be large enough for stockpiling RAP but actual RAP stockpiling was not confirmed.

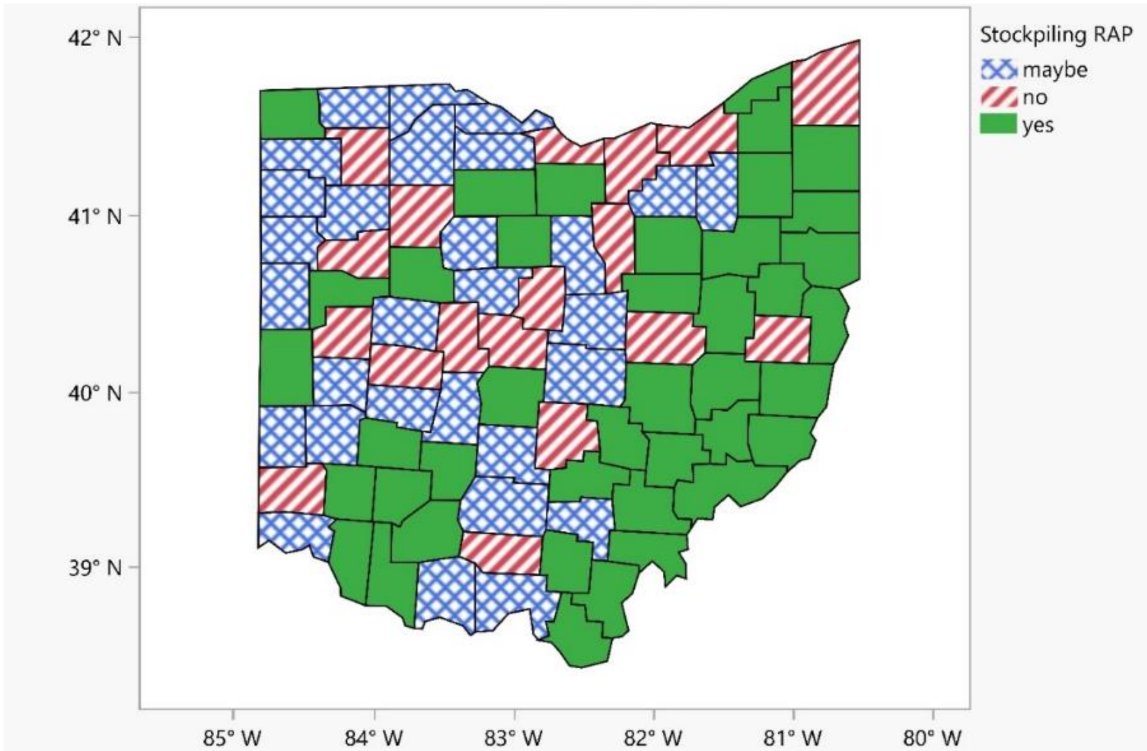


Figure 6-4 MAP of Counties stockpiling/not-stockpiling RAP based on informal Google Map aerial survey

In the interviews, a concern was there is excess RAP in the urban areas but a shortage in the rural areas. To better visualize the urban/rural areas in Ohio, the population by zip code was plotted in Figure 6-5. Interstate and interchange projects also tend to generate a significant amount of RAP.

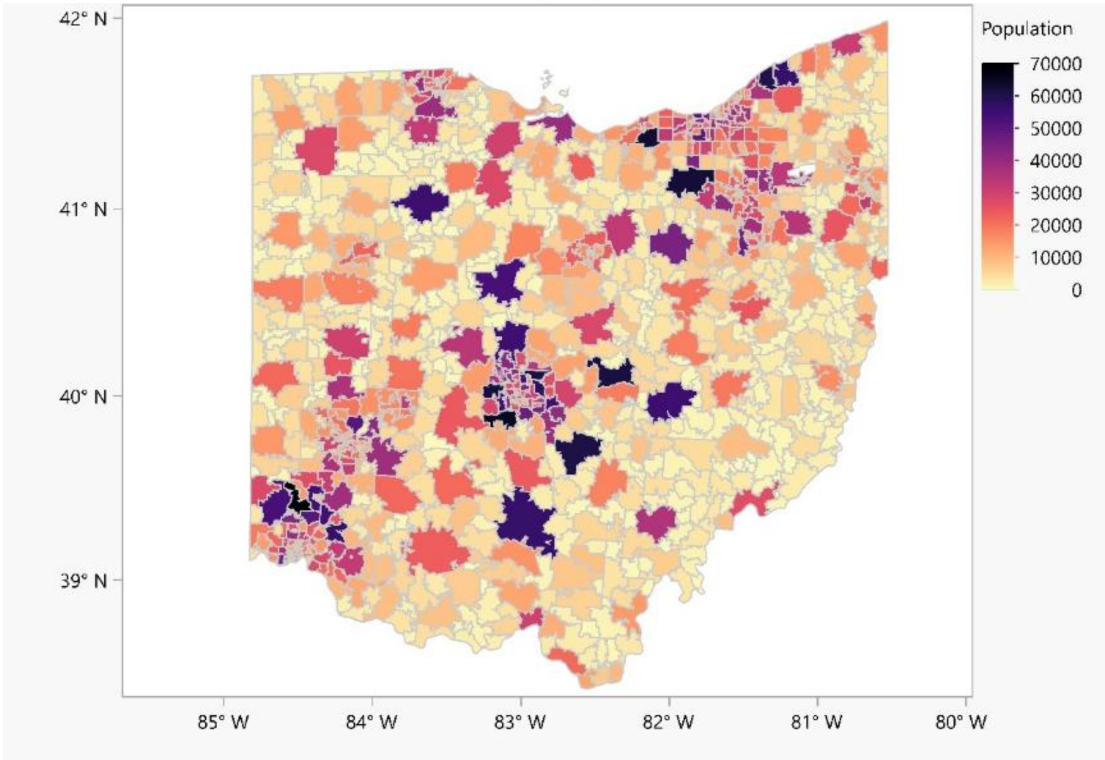


Figure 6-5 Ohio map of population by zip code

In addition to studying which agencies are stockpiling RAP, the availability of aggregates is important to this study. Figure 6-6 shows a map of certified aggregate suppliers in Ohio. The map was developed using list of certified aggregate suppliers in Ohio exported from Ohio DOT's website (http://odotextrpt.dot.state.oh.us/ViewReport.aspx?reportPath=/prd/CMSPortal/07000-MaterialsAndTesting-7015-CertifiedSuppliersAggregate).

The suppliers were mapped using google maps so agencies can visualize various options for obtaining aggregate materials. The map can be accessed with interactive features displaying the data from ODOT's supplier website when accessed online:
https://www.google.com/maps/d/edit?mid=1sm2NzyRCTGpmcgsPtDhGJxjfBkGUuc_l&usp=sharing

Many aggregate suppliers are located on major waterways in Ohio. The map in Figure 6-6 does not include suppliers outside the state of Ohio. An additional resource is Ohio's Division of Mineral Resources map of Ohio Mines within the state: https://gis.ohiodnr.gov/MapViewer/?config=OhioMines.

Figure 6-6 attempts to illustrate which areas may have more difficulty purchasing aggregates. Areas with aggregate deficiencies may have an increased incentive to utilize RAP from local projects. Haul costs can greatly factor into the decision of whether RAP or virgin aggregates will be most cost-effective for use in pavement preservation treatments.

It should be noted, Figure 6-6 provides a list of all certified aggregate suppliers in Ohio and is not specific to chip seal and microsurfacing aggregate. Through conversations with a contractor in Ohio who has experience designing and placing microsurfacing treatments, the number of suppliers that provide aggregate meeting ODOT's Item 421 microsurfacing specification is very limited. Based on phone interviews conducted in this study and a previous study on chip seal for local agencies in Ohio (Green et al., 2018) agencies in southeast Ohio indicated cost of limestone chip seal aggregate, especially that which met ODOT Item 422 specifications was prohibitively high.

Another factor that should be considered is the sustainability or life of an aggregate quarry. During the annual Ohio Transportation Engineering Conference in 2018, three presentations were dedicated to aggregate supply and demand (Shively, 2018; Cronin, 2018; and Barger, 2018). Both Barger and Shively discussed the shortfall of quality aggregate in Ohio. Barger detailed the numerous and at times prohibitive steps to open a new surface mine. While aggregate supplies are falling short it is becoming more and more difficult to provide new sources of aggregate. This will have a direct impact on availability and cost of aggregate for chip seal and microsurfacing at the local level.

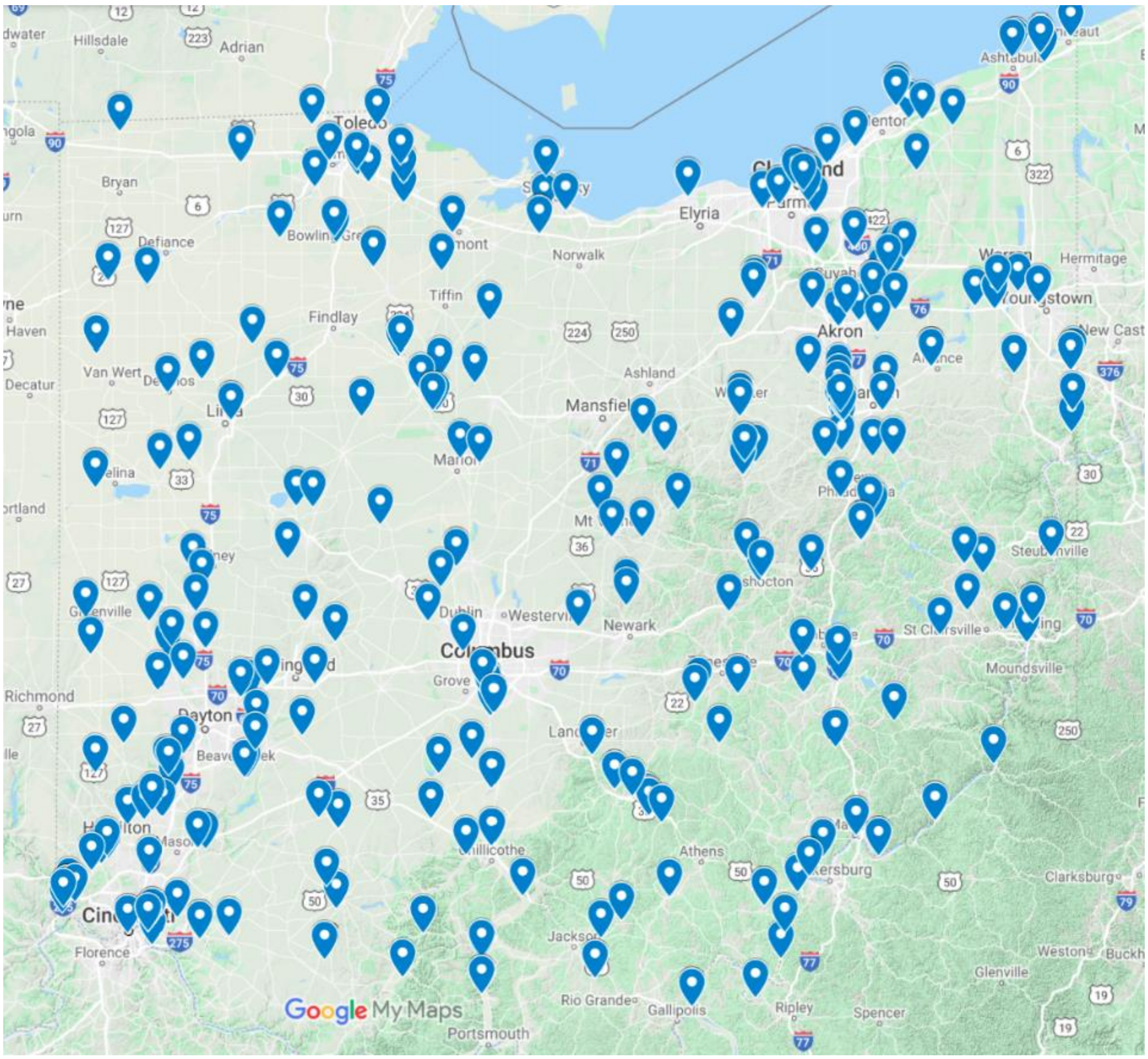


Figure 6-6 Map of Ohio DOT approved aggregate suppliers compiled using Google maps (Google Maps 2020).

6.2.1.3 Feasibility study of processing RAP, associated costs of RAP processing, and preliminary RAP gradation analysis

In addition to comparing base material costs, a feasibility analysis of the RAP material size distribution is an important consideration. Typical RAP material gradations for Ohio were analyzed to determine if the RAP materials in Ohio can be processed into a suitable gradation for use in chip seals and microsurfacing. It is important for each agency to determine whether RAP processing is needed and how much fractionation and specific sizes that are needed to meet typical chip seal and microsurfacing gradation requirements. An important consideration for chip seal aggregate is that too many RAP fines could clog a chip spreader, especially during warm weather. Chip seal aggregates should have a uniform grade and too many fines in the chip seal aggregate results in a reduced mean texture depth of the chip seal surface which may result in bleeding if fines are embedded in the binder.

The cost of hiring a contractor to process RAP is approximately $10/ton for small quantities (2,000-4,000 tons) and $8/ton for larger quantities. This estimate was provided by a local Ohio contractor, who specializes in processing RAP and has processed RAP in a neighboring state for use in chip seal, in February 2021. When planning to fractionate RAP, it is important to consider the extra space required for each additional stockpile. In special cases, there are subcontractors who can process larger pieces of RAP if the material was not milled. If the processed RAP material becomes too fine, this can be blended back with millings to achieve a more desirable gradation, depending on the final target gradation.

Data from a previous research project studying asphalt base materials in Ohio (Green et al., 2018) was used to determine a typical gradation distribution for RAP. The gradations were obtained from the RAP analysis performed for job mix formulas (JMFs) on 54 projects in Ohio. The RAP gradations provided in the JMF are for the extracted RAP aggregate. The box plots for the RAP gradation are shown in Figure 6-7. The box plots are used to summarize the data and indicate the distribution on each sieve size. The upper line of the box represents the 75th percentile and the lower line of the box represents the 25th percentile. The whiskers represent the lowest and highest quartiles of the data and individual dots represent outliers in the data. The side-by-side box plots allow comparison of distribution, an understanding of the gradation and gradations for pavement preservation treatments can also be compared.

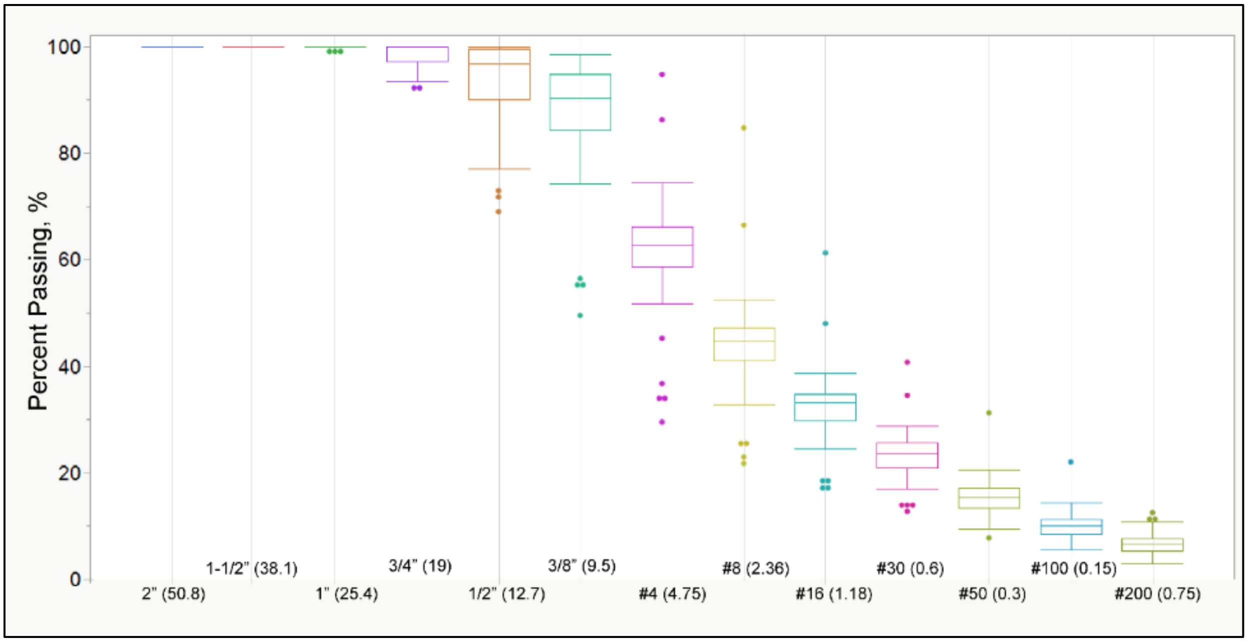


Figure 6-7 Typical Ohio RAP gradation represented in box plots showing the distribution of percent passing gradations for standard sieve sizes (RAP from 54 Ohio JMFs represented)

6.2.1.4 Comparing RAP gradations to Typical Gradations for Chip Seals and Microsurfacing

The ODOT gradations for chip seal and microsurfacing were compared and appear to be complementary with the chip seal gradation requiring a coarser, more-uniform aggregate gradation while the microsurfacing requires finer materials. Creating a chip seal aggregate from RAP will create left-over fine RAP material that may satisfy the microsurfacing gradation requirements. The combination of using RAP for chip seal and microsurfacing could help utilize the entire RAP gradation and create a valuable use for RAP fine materials.

The chip seal gradations from Ohio DOT are shown in Table 6-2. Based on past research, many local agencies use ODOT's 2002 chip seal specification because the aggregates have shown to perform adequate for low-volume roads and cost less compared to the newer specification.

Table 6-2 ODOT 2002 and 2019 chip seal gradation requirements

Sieve Size	Total Percent Passing for Ohio DOT 2002 chip seal specification	Total Percent Passing for 2019 Ohio DOT Type A Chip Seal Specification	Total Percent Passing for 2019 Ohio DOT Type B Chip Seal Specification
1/2 inch (12.5 mm)	100	100	100
3/8 inch (9.5 mm)	85 to 100	85 to 100	100
No. 4 (4.75 mm)	10 to 30	5 to 25	85 to 100
No. 8 (2.36 mm)	0 to 10	0 to 10	5 to 30
No. 16 (1.18 mm)	0 to 5	0 to 5	0 to 10
No. 200 (75 µm)	2.0 max[1]	0 to 1.5[1]	0 to 1.5[1]
[1] Washed gradation value			

The RAP gradation summary from 54 Ohio JMFs were compared to chip seal gradations and microsurfacing gradations. Figure 6-8 shows the 2002 Ohio DOT chip seal gradation and Figure 6-9 shows the current Ohio DOT chip seal gradations. The uniform nature of the chip seal gradations will require RAP processing; however, the RAP may still be a cost-effective option in some instances. Also, if there is a RAP surplus in Ohio, as indicated in the NAPA survey, using RAP in pavement preservation would be an opportunity to use more amounts of recycled material to reduce any large surplus.

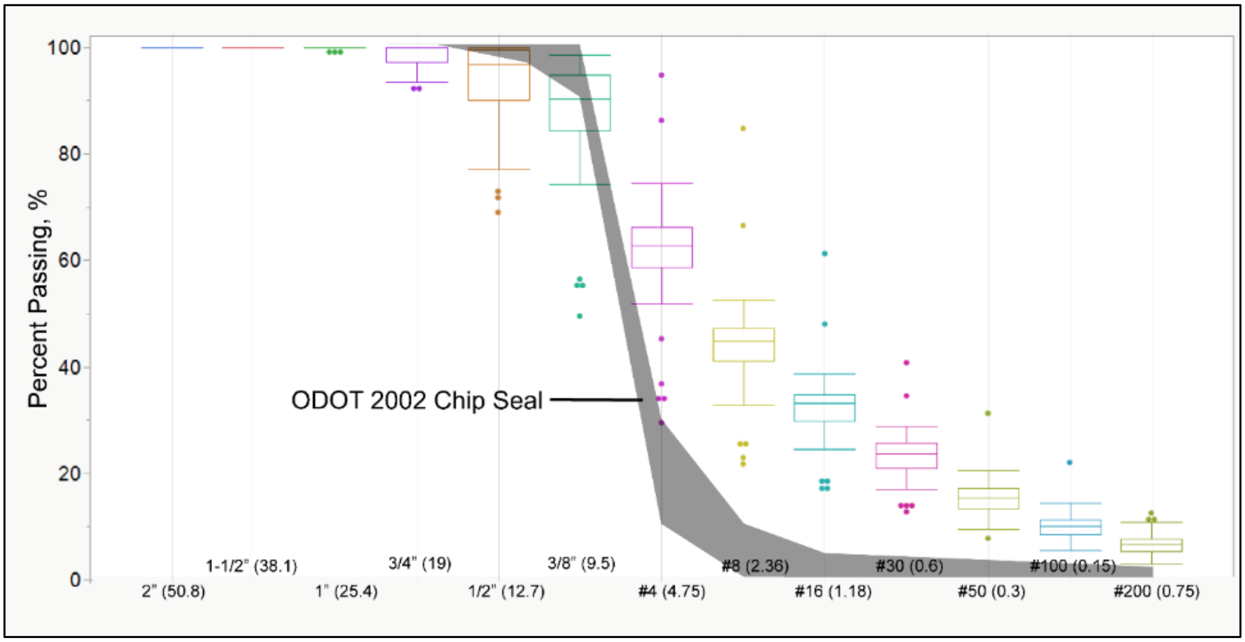


Figure 6-8 Comparison between RAP gradation and 2002 Ohio DOT chip seal gradation

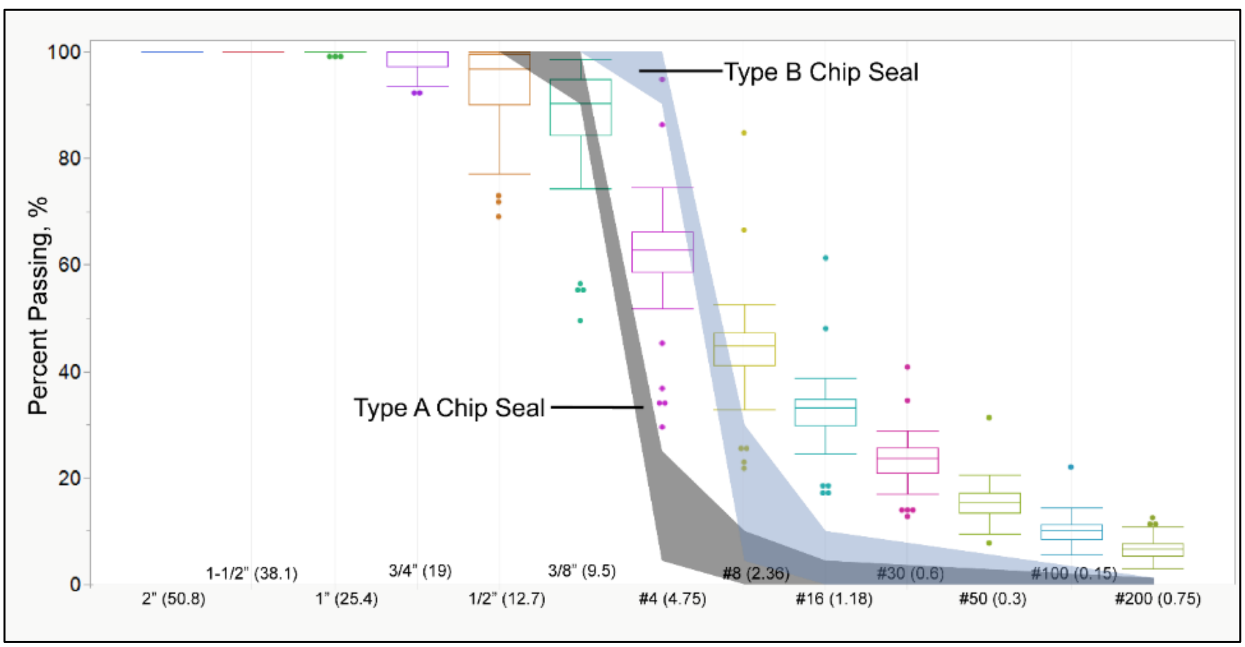


Figure 6-9 Comparison between RAP gradation and Type A and Type B chip seal gradations in 2019 Ohio DOT specification

The RAP gradations were also compared with ODOT microsurfacing gradations (listed in Table 6-3). The microsurfacing gradations were compared with the RAP gradation distributions and the results are shown in Figure 6-10. When comparing the chip seal gradation curves and the microsurfacing gradation curves to the RAP gradation distributions, there is evidence that RAP could likely be processed into chip seal material while simultaneously producing gradations favorable to microsurfacing gradations.

Table 6-3 Microsurfacing gradations required by Ohio DOT 2019 specification (ODOT 2019)

Sieve Size	Total Percent Passing	
	A	B
3/8 inch (9.50 mm)	100	100
No. 4 (4.75 mm)	85 to 100	70 to 90
No. 8 (2.36 mm)	50 to 80	45 to 70
No. 16 (1.18 mm)	40 to 65	28 to 50
No. 30 (600 µm)	25 to 45	19 to 34
No. 50 (300 µm)	13 to 25	12 to 25
No. 100 (150 µm)	--	7 to 18
No. 200 (75 µm)	5 to 15	5 to 18

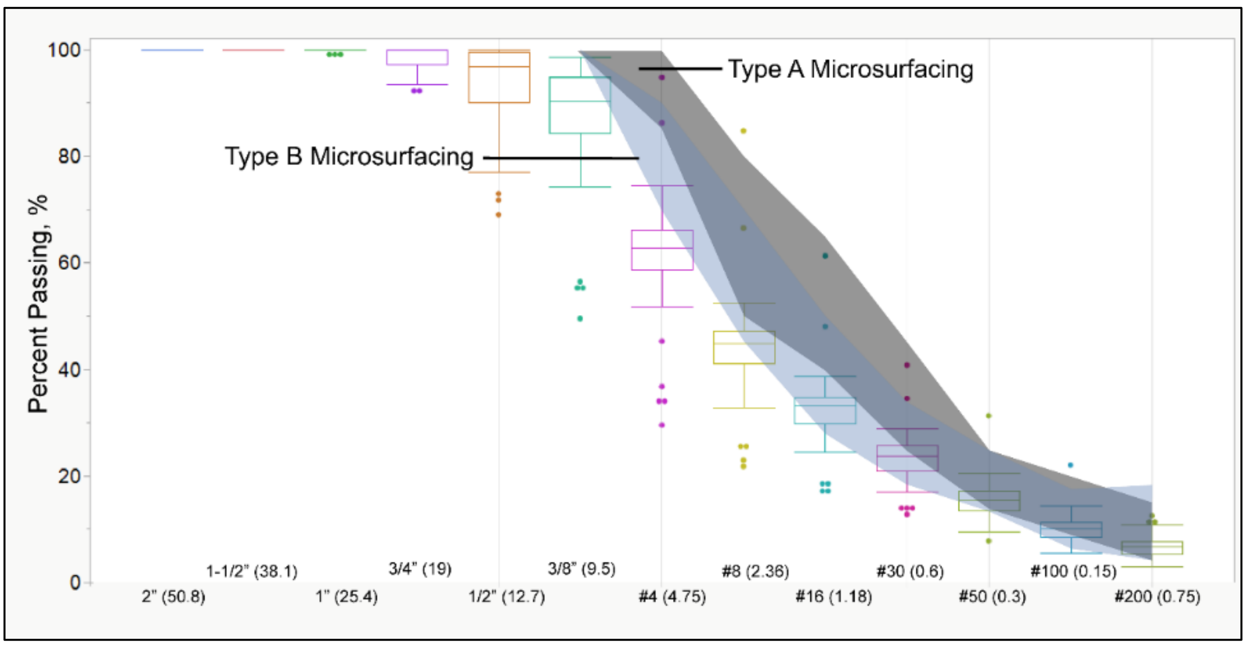


Figure 6-10 Comparison between RAP gradation and Type A and Type B microsurfacing gradations in 2019 Ohio DOT specification

6.2.2 Hauling Cost Considerations

Haul costs can vary significantly based on the region, current market condition, and availability. There are multiple ways to estimate aggregate hauling costs and the price will fluctuate based on numerous variables. One standard approach to calculating haul costs is the first mile price is a mobilization cost with additional mileage costs divided into two groups: <30 miles unit price and >30 miles unit price. Hauling costs will depend on the size, duration (speed), and cycle length and each situation will be unique. Example price estimates for hauling are shown in loose cubic yard (L.C.Y.) in Table 6-4. The table shows the differences between trucks of two different sizes, each truck's daily output and expected total for overhead and profit. Another example analysis is shown in Figure 6-11 which demonstrates how speed (mph) and cycle length (mileage) can influence the cost of hauling materials.

Table 6-4 Example price estimates for loose cubic yard (Waier et al., 2010)

Description	UNIT	Daily Output	Qty.	Extended Total O&P*
12 CY truck, 15 min wait, 35 MPH, cycle 20 mile	L.C.Y.	120	1000	$10,480
18 CY truck, 8 wheels, 15 min wait, 35 MPH, cycle 20 mile	L.C.Y.	162	1000	$8,940

*Overhead and Profit

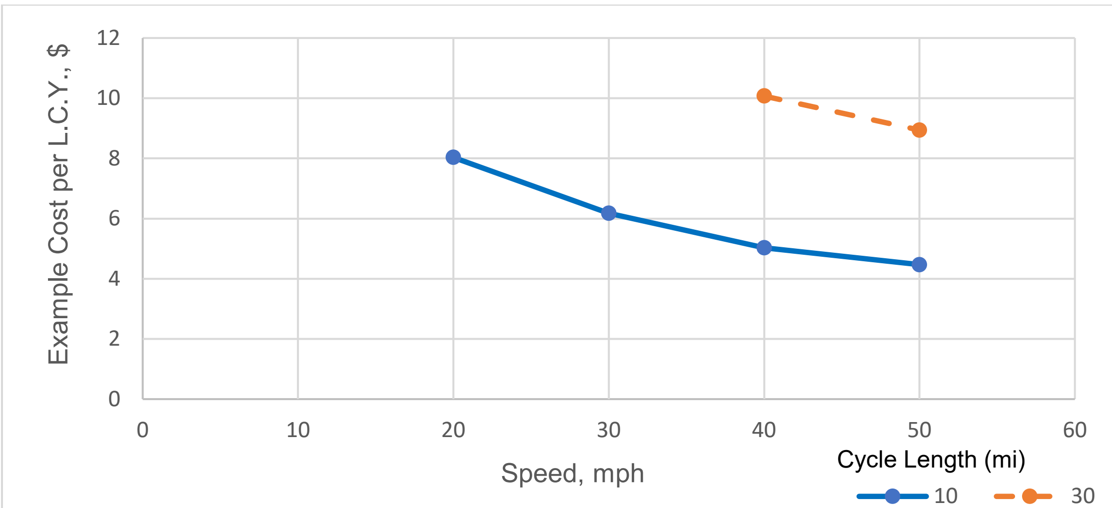


Figure 6-11 Example cost analysis for hauling costs

Hauling related costs are highly variable and the best way to obtain accurate costs is for agencies to solicit bids from contractors and select the lowest responsive bid to perform the work. Purchasing aggregates and hauling aggregates is generally based on a $/ton hauling cost for a specific project with known distances.

The research team found a wide range of hauling cost estimates from interviews. An interview with a road superintendent for a city estimated they had a project where hauling costs were approximately $6/ton (not including material costs). A material supplier was interviewed and estimated that for a hauling distance of 35 miles or less, the aggregate will cost is $10-12/ton. If the haul distance is longer, the cost increases to $15-18/ton. The unit hauling costs also will be quantity dependent.

6.2.2.1 Example 1: Comparing of an agency purchasing RAP vs. using virgin aggregate for surface treatments

The purpose of this example is to compare the cost estimates for purchasing RAP vs. using virgin aggregate for surface treatments. This analysis assumes 100% of the RAP pile can be processed into suitable chip seal and microsurfacing gradations. This analysis assumes 30% of the RAP stockpile is used as chip seal aggregate and 70% is used for the microsurfacing aggregate. Agencies must consider whether aggregate material quantities obtained from processing RAP for chip seal and microsurfacing (to meet gradation requirements) align with the chip seal and microsurfacing project quantities based on lbs/sy estimates. For this project, assume microsurfacing aggregate is placed at 20 lbs/sy and assume chip seal aggregate is placed at a rate of 20 lbs/sy. For calculating quantities, the agency has a 9 lane-mile chip seal project and a 21 lane-mile microsurfacing project.

The aggregate requirement for the 9 lane-mile chip seal is calculated based on the following and rounded up to the nearest ton:

$$Chip\ seal\ aggregate\ in\ lbs = 12\frac{ft}{lane} \times 9\ lane\ miles \times 5280\frac{ft}{mile} \times \frac{1\ SY}{9\ ft^2} \times 20\frac{lbs}{SY} \times \frac{1\ ton}{2000\ lbs}$$
$$= 634\ tons$$

The aggregate requirement for the 21 lane-mile microsurfacing is calculated based on the following and rounded up to the nearest ton:

$$Microsurfacing\ aggregate\ in\ tons$$
$$= 12\frac{ft}{lane} \times 21\ lane\ miles \times 5280\frac{ft}{mile} \times \frac{1\ SY}{9\ ft^2} \times 20\frac{lbs}{SY} \times \frac{1\ ton}{2000\ lbs}$$
$$= 1479\ tons\ of\ microsurfacing\ aggregate$$

The total tonnage required for RAP is approximately 2,113 tons. Generally, quantities would allocate extra material but for the purpose of this comparison, no excess is incorporated. Virgin aggregate cost for chip seal, \$19/ton, and virgin aggregate cost for microsurfacing, \$23/ton, were based on costs provided in survey responses by local agencies, and costs provided by an Ohio material supplier and contractor, respectively.

The activities for the RAP purchasing alternative in this analysis are:

1. Purchase RAP from contractor
2. Haul RAP to agency location
3. Process RAP for use in chip seal and microsurfacing
4. Agency places chip seal and agency solicits bids for microsurfacing project that uses the agency's RAP as the microsurfacing aggregate

The activities for the virgin aggregate alterative in this analysis are:

1. Purchase virgin aggregate from material supplier for chip seal
2. Haul chip seal aggregate to agency
3. Solicit bids for a microsurfacing project (related cost is the virgin aggregate)
4. Agency places chip seal with virgin aggregate

There are environmental considerations for this example that are difficult to quantify. Virgin aggregate must still be processed into respective gradations like the RAP material, but the processing costs of virgin material are included in the base price. The cost analysis for Example 1 is provided in Table 6-5.

Table 6-5 Example 1: Comparing purchasing RAP vs. virgin aggregate

Description	Activity #1	Activity #2	Activity #3	Activity #4	Total aggregate cost comparison
RAP Alternative Description	Purchase 2,113 tons of RAP from Contractor	Haul 2,113 tons of RAP to agency location	Process RAP for use in chip seal and microsurfacing (small quantity)	Surface treatment construction	--
Purchasing RAP Related Unit Cost	$20/ton	$10/ton	$10/ton	Assume no difference in construction costs between alternatives	$40/ton
Purchasing RAP Alternative Total Cost	**$42,260**	**$21,130**	**$21,130**	**--**	**$84,520**
Virgin Agg. Alternative Description	Agency purchases 634 tons of virgin chip seal aggregate	634 tons of virgin chip seal aggregate is hauled to agency	Agency solicits bids for microsurfacing project and pays for 1479 tons of virgin microsurfacing aggregate and hauling as a bid item in the project	Surface treatment construction	--
Virgin Agg. Related Unit Cost	$19/ton	$10/ton	$23/ton for virgin aggregate material and $10/ton for hauling	Assume no difference in construction costs between alternatives	--
Total Virgin Agg. Related Cost	**$12,046**	**$6,340**	**$48,807**	**--**	**$67,193**

Based on this preliminary estimate, purchasing and processing RAP costs adds significant cost to the project. This analysis also assumes there is no value to the asphalt binder in the RAP and the asphalt binder in the RAP was not accounted for in in the aggregate quantity estimate. (In other words, RAP is treated like a “black rock” and the aggregate quantity for the RAP alternative was not assumed to be 5% higher even though RAP is generally ~5% asphalt binder). Based on the assumed costs shown here, if RAP could be purchased for $11.80/ton or less (($67,193-$21,130-$21,130)/2113 tons), the cost for RAP as an alternative to virgin aggregate in chip seal and microsurfacing would be equivalent or less than the cost of using virgin aggregate. Four of the six agencies which provided a cost for purchasing RAP indicated the price was $12 or less, therefore, purchasing may be an economical alternative to using virgin aggregate.

6.2.2.2 Example 2: Analysis comparing an agency retaining millings from a project vs. using virgin aggregate for surface treatment

This example builds from the previous section but instead of the agency purchasing RAP, in this example they are retaining millings from a project. Retaining millings is compared against using virgin aggregate for the surface treatment. The assumptions are similar to example 1 and include:

- Agency has a project where retaining RAP is feasible
- 100% of the RAP pile can be used.
- 30% RAP stockpile meets the chip seal gradation and 70% meets microsurfacing gradation requirements.
- Chip seal is a 9 lane-mile project requiring 634 tons.
- Microsurfacing is a 21 lane-mile project requiring 1479 tons.
- Excess aggregate allowances are not included in the cost.
- Assume 2113 tons of aggregate are needed in total.
- Asphalt content is not deducted from the weight of the RAP.

The activities for retaining RAP alternative in this analysis are:

1. Agency retains RAP from an agency project. This activity cost is assumed to include costs related to hauling RAP to agency location. This cost, $5/ton, was provided by a local agency and was based on actual cost for retaining RAP from a project.
2. Process RAP for use in chip seal and microsurfacing
3. Agency places chip seal and agency solicits bids for microsurfacing project that uses the agency's RAP as the microsurfacing aggregate

Repeated from Example 1, the activities for the virgin aggregate alterative in this analysis are:

1. Purchase virgin aggregate from material supplier for chip seal
2. Haul chip seal aggregate to agency
3. Solicit bids for a microsurfacing project (related cost is the virgin aggregate)
4. Agency places chip seal with virgin aggregate

The activities and costs for this alternative are summarized in Table 6-6.

Table 6-6 Example 2: Comparing purchasing RAP vs. virgin aggregate

Description	Activity #1	Activity #2	Activity #3	Activity #4	Total aggregate cost comparison
RAP Alternative Description	Retain 2113 tons of RAP from agency project	Process RAP for use in chip seal and microsurfacing (Small quantity unit price)	Surface Treatment construction	--	--
Retaining RAP Related Unit Cost	$5/ton	$10/ton	Assume no difference in construction costs between alternatives	--	$15/ton
Retaining RAP Alternative Total Cost	**$10,565**	**$21,130**	**--**		**$31,695**
Virgin Agg. Alternative Description	Agency purchases 634 tons of virgin chip seal aggregate	634 tons of virgin chip seal aggregate is hauled to agency	Agency solicits bids for microsurfacing project and pays for 1,479 tons of virgin microsurfacing aggregate and hauling as a bid item in the project	Surface Treatment construction	--
Virgin Agg. Related Unit Cost	$19/ton	$10/ton	$23/ton for virgin aggregate material and $10/ton for hauling	Assume no difference in construction costs between alternatives	--
Total Virgin Agg. Related Cost	**$12,046**	**$6,340**	**$48,807**	**--**	**$67,193**

Based on this preliminary estimate, significant cost savings can be achieved if millings from an agency-owned project can be retained. Assuming an agency has a situation similar to the scenario and costs presented in the analysis, retaining millings from a project is the preferred cost alternative for the three alternatives compared. Based on the assumptions presented in Examples 1 and 2, purchasing RAP from a contractor at costs similar to virgin aggregate is not cost effective for a local agency. In addition, the RAP material generally requires additional processing incurring additional cost.

7 Characterization of RAP for use in Microsurfacing and Chip Seals on Local Roadways

7.1 Existing Specifications and Requirements for use of RAP in Pavement Preservation Treatments

Through the literature review 10 agencies or organizations were identified which have placed preservation treatment(s) with RAP, as shown in Table 7-1. The majority of the agencies listed were contacted with a request to complete a questionnaire or discuss the questionnaire over a phone interview. Five agencies/organizations responded to the request, as indicated in the table below. Agencies were asked to provide any requirements or specifications related to RAP for use in pavement preservation treatments. Requirements for RAP used in chip seal or microsurfacing are summarized in the following subsections based on the information provided to the research team and information identified in the recently published FHWA report on RAP in pavement preservation treatments (Duncan et al., 2020). For reference, ODOT specifications for virgin aggregate used in chip seal and microsurfacing treatments are also summarized in the following subsections.

Table 7-1 Agencies/Organizations having experience with pavement preservation treatments containing RAP

Agency/Organizations	Treatments with RAP	Source
Caltrans Maintenance	Chip seal	(Emerson, 2015)
City of Bakersfield, CA	Cape seal	(Hitti, E., 2014)
City of Colton, CA	Slurry seal	(Udelhofen, 2008)
City of Port Hueneme, CA	Microsurfacing	(Metcalf, 2016)
Los Angeles County, CA*	Scrub seal, microsurfacing, slurry seal	(LA County Department of Public Works, 2015; Updyke and Ruh, 2016)
Mohave County, AZ	Chip seal	(Emerson et al., 2018)
National Center for Asphalt Technology (NCAT) at Auburn University*	Chip seal	(Kessler et al., 2019)
New Mexico Department of Transportation (NMDOT)*	Chip seal	(Tarefder and Ahmad, 2018)
Pennsylvania Department of Transportation (PennDOT)*	Chip seal	(Jahangirnejad et al., 2019)
San Bernardino County, CA*	Chip seal	(Emerson, 2015)

*Responded to request for questionnaire/phone interview

7.1.1 Existing Specifications/Requirements for RAP in Chip Seals

Specifications related to the gradation of RAP for use in chip seal were identified for three agencies, LA County, NMDOT and PennDOT, and are summarized in Table 7-2. All three agencies allow 100% RAP in chip seal treatments. LA County allows the use of RAP screenings in Polymer Modified Emulsion Chip seal as well as Asphalt Rejuvenating Emulsion Chip Seals (LA County DPW, 2015). Screenings must meet gradation requirements in Section 200-1.2.2.2 of the 2018 Greenbook (SSPWC, 2018). As reported in the FHWA report (Duncan et al., 2020), the medium fine gradation is the most designated size for RAP Chip Seal in LA County. NMDOT provided the research team with the "Special Provisions for Section 410: Stockpiled Surface Treatment Aggregate ½", Department-Furnished Reclaimed Asphalt Pavement (RAP)," which lists gradation requirements for stockpiled surface treatment ½" aggregate. In which it states, "the aggregate is crushed stone or crushed gravel, composed of hard durable pebbles or fragments derived from existing stockpiled RAP." These gradation requirements differ from those reported in the FHWA report on RAP in pavement preservation treatments (Duncan et al., 2020). Therefore, both gradation bands are reported in Table 7-2.

Table 7-2 Summary of RAP Gradation Specifications for use in Chip Seal *after* (Duncan et al., 2020, PennDOT, 2020, and SSPWC, 2018)

	NMDOT	NMDOT*	PennDOT	Green Book Coarse (1/2" x #4)	Green Book Medium (3/8" x #6)	Green Book Medium Fine (5/16" x #8)	Green Book Fine (1/4" x #10)
Sieve Size	**% Passing**						
3/4" (19 mm)	100			100			
1/2" (12.5 mm)	95 - 100	100	100	85 - 100	100		
3/8" (9.5 mm)	0 - 70	-	85 - 100	0 - 30	85 - 100	100	100
No. 4 (4.75 mm)	0 - 6	0 - 6	0 - 30	0 -5	0 - 15	0 - 50	60 - 85
No. 8 (2.36 mm)			0 - 15		0 - 5	0 - 15	0 - 25
No. 10 (2.00 mm)	0 – 2	0 - 4					
No. 16 (1.18 mm)			0 - 10			0 - 5	0 - 5
No. 30 (0.600 mm)						0 - 3	0 - 3
No. 50 (0.300 mm)							
No. 200 (0.075mm)	N/A	0 - 2**	0 - 1**	0 - 2**	0 - 2**	0 - 2**	0 - 2**
*From 2019 Special Provisions for Section 410							
**washed gradation value							

Local agencies in Ohio were asked as part of a survey for this project the size and type of aggregate used for chip seal and microsurfacing. Most agencies indicated a No. 8 sized stone was used in their jurisdiction. Gradation bands vary from agency to agency. However, PennDOT and the Green Book Medium (3/8" x No. 6) gradation requirements most closely resemble an AASHTO No. 8 gradation, presented in Table 7-3 below for reference.

Table 7-3 AASHTO No. 8 and No. 9 Gradations (ODOT, 2019)

	AASHTO No. 8	AASHTO No. 9
Sieve Size	**% Passing**	
3/4" (19 mm)		
1/2" (12.5 mm)	100	
3/8" (9.5 mm)	85 - 100	100
No. 4 (4.75 mm)	10 - 30	85 - 100
No. 8 (2.36 mm)	0 - 10	10 - 40
No. 10 (2.00 mm)		
No. 16 (1.18 mm)	0 - 5	0 - 10
No. 30 (0.600 mm)		
No. 50 (0.300 mm)		0 - 5
No. 200 (0.075mm)		
**washed gradation value		

Gradation specifications were the most common requirements reported for RAP used in chip seal treatments among the three agencies. LA County (LA County DPW, 2015) does specifies for RAP used in chip seal, a minimum sand equivalence value of 80%, following the California Test Method (CTM) 217 and a maximum of 45% mass loss after 500 revolutions in the LA Abrasion test.

7.1.2 Specifications for Virgin Chip Seal Aggregate

In a previous study on chip seals for local agencies in Ohio (Green et al., 2018), agencies reported they largely follow ODOT specifications for chip seal from the 2002 Construction and Materials Specifications (CMS) or the recent version of the specification. Listed in Table 7-4 are the gradation requirements for ODOT (2002) chip seal aggregate and ODOT (2019) Item 422 Type A and Type B gradation requirements.

Table 7-4 ODOT 2002 and 2019 Chip Seal Gradation Requirements

	ODOT 2002	ODOT Type A (2019)	ODOT Type B (2019)
Sieve Size	% Passing		
1/2 inch (12.5 mm)	100	100	100
3/8 inch (9.5 mm)	85 to 100	85 to 100	100
No. 4 (4.75 mm)	10 to 30	5 to 25	85 to 100
No. 8 (2.36 mm)	0 to 10	0 to 10	5 to 30
No. 16 (1.18 mm)	0 to 5	0 to 5	0 to 10
No. 200 (0.075 mm)	2.0 max[1]	0 to 1.5[1]	0 to 1.5[1]
[1] Washed gradation value			

The ISSA has published recommended performance guidelines for chip seals, A165 (2012), in which three gradation bands are recommended, depending on the type of chip seal selected. Gradations as shown in ISSA A165 are presented in Table 7-5.

Table 7-5 ISSA Recommended Chip Seal Gradations (ISSA A165)

	Type I	Type II	Type III
Sieve Size	% Passing		
3/4 inch (19 mm)	100	100	100
1/2 inch (12.5 mm)	100	100	95 – 100
3/8 inch (9.5 mm)	100	95 – 100	0 -15
1/4 inch (6.3 mm)	95 – 100	0 – 35	0 – 10
No. 8 (2.36 mm)	0 – 3.0	0 – 3.0	0 – 3.0
No. 200 (0.075 mm)	0 – 1.0[1]	0 – 1.0[1]	0 – 1.0[1]
[1] Washed gradation value			

In addition to gradation, ODOT has specifications for other aggregate properties for virgin chip seal aggregate, such as sodium sulfate soundness, percent wear by LA Abrasion test, and fractured faces. Likewise, ISSA also lists recommended minimum requirements for flat and elongated particles, fractured faces, and resistance to degradation by LA Abrasion test for virgin chip seal aggregate. Such requirements are summarized in Table 7-6. In addition to these requirements, the Minnesota Seal Coat Handbook (Wood et al., 2006) recommends aggregate with flakiness index less than 25% be utilized for chip seal.

Table 7-6 Summary of Additional Requirements for Virgin Chip Seal Aggregate, *after* (ISSA A165 (2012), and ODOT, 2019).

Aggregate Type	Test	Spec	Criteria	Source
Virgin (Fine)	Sodium sulfate soundness	AASHTO T 104	Max 15% loss	ODOT Item 703.05
Virgin (Fine)	Aggregations of soil, silt, etc.		Max 0.5% by weight	ODOT Item 703.05
Virgin (Coarse)	Percent wear, LA Abrasion test	AASHTO T 96 or ASTM C 535	Max. 40%	ODOT Item 703.05
Virgin (Coarse)	Unit weight, compacted slag	AASHTO T 19	Min. 70 lb/ft^3 (1120 kg/m3)	ODOT Item 703.05
Virgin (Coarse)	Sodium sulfate soundness	AASHTO T 104	Max 12% loss	ODOT Item 703.05
Virgin (Coarse)	Percent by weight of fractured pieces		Min. 40%	ODOT Item 703.05
Virgin (Coarse)	Micro-Deval Abrasion loss test (gravel only)	AASHTO T 327	Max. 20%	ODOT Item 703.05
Virgin	Flat and elongated particles	ASTM D 4791	Ratio of 3:1 < 12%	ISSA A165
Virgin	Fractured Face	AASHTO T 335 or ASTM D 5821	100%	ISSA A165
Virgin	Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles Machine	AASHTO T 96 or ASTM C 131	Max. 25%	ISSA A165

7.1.3 Existing Specifications/Requirements for RAP in Microsurfacing

Specifications for RAP in microsurfacing were identified for only one agency, LA County, in which requirements are provided for unextracted RAP and extracted RAP gradations, as reported by Duncan et al. (2020). The RAP gradation requirements along with the minimum asphalt content requirement are shown in Table 7-7. As reported in the FHWA report (Duncan et al., 2020), LA County also lists requirements for RAP for sand equivalence, soundness, and durability, as listed in Table 7-8.

Table 7-7 LA County RAP Gradation Requirements for use in Microsurfacing *after* (Duncan et al., 2020)

	Unextracted RAP	Extracted RAP Aggregate
Sieve Size	**% Passing**	
3/8" (9.5 mm)	100	100
No. 4 (4.75 mm)	95 - 100	95 - 100
No. 8 (2.36 mm)	65 - 85	70 - 90
No. 16 (1.18 mm)	35 - 60	50 - 75
No. 30 (0.600 mm)	18 - 38	35 - 55
No. 50 (0.300 mm)	8 - 25	22 - 40
No. 100 (0.150 mm)	5 - 20	13 - 38
No. 200 (0.075mm)	2 - 12	5 - 15
Residual Asphalt Content		6.5% Min

Table 7-8 LA County RAP Requirements for use in Microsurfacing *after* (Duncan et al., 2020)

Test	Spec	Requirement
Durability	CTM 229	55%, min.
LA Abrasion (RAP Retained on No. 4 sieve)	ASTM C131	35%, max.
Sand Equivalence	ASTM D2419	60%, min.
Soundness (5 cycles)	ASTM C88	15.0%, maximum

7.1.4 Specifications for Virgin Microsurfacing

ODOT lists gradation requirements for two types of microsurfacing under ODOT Item 421 (2019). Type A microsurfacing is used for surface courses, whereas Type B is used for rut fill courses. Gradations for both types are presented in Table 7-9.

Table 7-9 ODOT 2019 Microsurfacing Gradation Requirements (ODOT 2019)

	Type A	Type B
Sieve Size	**% Passing**	
3/8 inch (9.50 mm)	100	100
No. 4 (4.75 mm)	85 to 100	70 to 90
No. 8 (2.36 mm)	50 to 80	45 to 70
No. 16 (1.18 mm)	40 to 65	28 to 50
No. 30 (600 µm)	25 to 45	19 to 34
No. 50 (300 µm)	13 to 25	12 to 25
No. 100 (150 µm)	--	7 to 18
No. 200 (75 µm)	5 to 15	5 to 18

ISSA has published recommended performance guidelines for micro surfacing, A143 (2010), in which two gradation bands are recommended, depending on the type of micro surfacing selected. Gradations as shown in ISSA A165 are presented in Table 7-10.

Table 7-10 ISSA A143 Microsurfacing Gradation Requirements (ISSA, 2010)

	Type II	Type III
Sieve Size	**% Passing**	
3/8 inch (9.50 mm)	100	100
No. 4 (4.75 mm)	90 – 100	70 – 90
No. 8 (2.36 mm)	65 – 90	45 – 70
No. 16 (1.18 mm)	45 – 70	28 – 50
No. 30 (600 µm)	30 – 50	19 – 34
No. 50 (300 µm)	18 – 30	12 – 25
No. 100 (150 µm)	10 – 21	7 – 18
No. 200 (75 µm)	5 – 15	5 – 15

In addition to gradation, ODOT lists requirements for virgin microsurfacing aggregate, such as sodium sulfate soundness, percent wear by LA Abrasion test, and fractured faces. Likewise, ISSA also lists recommended minimum requirements for flat and elongated particles, fractured faces, and resistance to degradation by LA Abrasion test for virgin microsurfacing aggregate. Such requirements are summarized in Table 7-11.

Table 7-11 Summary of Additional Requirements for Virgin Microsurfacing Aggregate, *after* (ISSA A143 (2010), and ODOT, 2019).

Aggregate Type	Test	Spec	Criteria	Source
Virgin	Percent by weight of fractured pieces		100	ODOT Item 421
Virgin	Sand equivalence	AASHTO T 176	Min. 55	ODOT Item 421
Virgin (Fine)	Sodium sulfate soundness	AASHTO T 104	Max 15% loss	ODOT Item 703.05
Virgin (Fine)	Aggregations of soil, silt, etc.		Max. 0.5% by weight	ODOT Item 703.05
Virgin (Coarse)	Percent wear, LA Abrasion test	AASHTO T 96 or ASTM C 535	Max. 40%	ODOT Item 703.05
Virgin (Coarse)	Unit weight, compacted slag	AASHTO T 19	Min. 70 lb/ft^3 (1120 kg/m3)	ODOT Item 703.05
Virgin (Coarse)	Sodium sulfate soundness	AASHTO T 104	Max 12% loss	ODOT Item 703.05
Virgin (Coarse)	Micro-Deval Abrasion loss test (gravel only)	AASHTO T 327	Max. 20%	ODOT Item 703.05
Virgin	Sieve Analysis	AASHTO T 27 or ASTM C 136 and AASHTO T 11 or ASTM C 117	ISSA A143 – 4.2.3	ISSA A143 (Microsurfacing)
Virgin	Sand equivalence	AASHTO T 176 or ASTM D 2419	Min. 65	ISSA A143 (Microsurfacing)
Virgin	Soundness of aggregate	AASHTO T 104 or ASTM C 88	Max. 15% with Sodium sulfate Max. 25% with Magnesium sulfate	ISSA A143 (Microsurfacing)
Virgin	Resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles Machine	AASHTO T 96 or ASTM C 131	Max. 30%	ISSA A143 (Microsurfacing)

7.2 Analysis of RAP Gradations

Data from a previous research project studying asphalt base materials in Ohio (Green et al., 2018) were used to determine a typical gradation distribution for RAP. The gradations were obtained from the RAP analysis performed for job mix formulas (JMFs) for projects constructed for ODOT. The RAP gradations provided in the JMF are for the extracted RAP aggregate. Initially, box plots for RAP gradations from 54 projects across the state, were developed, and are shown in Figure 7-1. The box plots are used to summarize the data and indicate the distribution on each sieve size. The upper line of the box represents the 75th percentile and the lower line of the box represents the 25th percentile. The whiskers represent the lowest and highest quartiles of the data and individual dots represent outliers in the data. The side-by-side box plots allow comparison of distribution, an understanding of the gradation and gradations for pavement preservation treatments can also be compared. These box plots reveal there is large variability among the RAP gradations, particularly at the 1/2" (12.5 mm) to the No. 8 (2.36 mm) sieves.

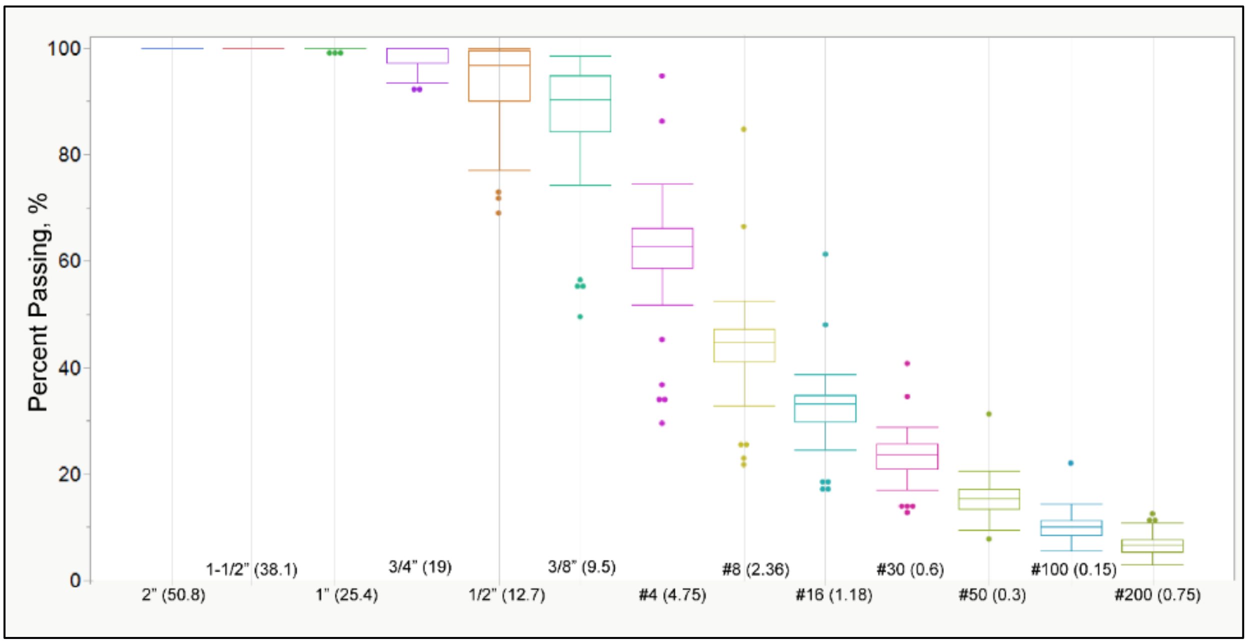


Figure 7-7-1 Distribution of Typical RAP Gradations in Ohio

The extracted RAP gradations from the initial 54 JMFs were for asphalt base mixes, therefore extracted RAP gradations from another 101 JMFs which included mostly asphalt surface and intermediate mixes, as well as some asphalt base mixes were added to the dataset. The average percent passing each sieve is listed in Table 7-12 by region as well as statewide, additionally, the average asphalt content is also provided. While average values for the initial evaluation of 54 JMFs were slightly coarser, the differences between extracted RAP gradations in the first 54 JMFs and the final 155 were small (4% or less on a given sieve). In looking at the average gradation by region, there does not appear to be significant differences among the four regions.

Table 7-12 Extracted RAP Gradations from Historical JMFs, Average Percent Passing

	NE	NW	SE	SW	Statewide
Sieve Size (mm)	% Passing				
2" (50.8)	100	100	100	100	100
1-1/2" (38.1)	100	100	100	100	100
1" (25.4)	100	100	100	100	100
3/4" (19)	99	98	100	99	99
1/2" (12.5)	97	93	99	97	96
3/8" (9.5)	91	86	94	90	90
#4 (4.75)	65	61	65	63	63
#8 (2.36)	46	43	47	46	46
#16 (1.18)	35	31	35	34	33
#30 (0.6)	25	22	25	24	24
#50 (0.3)	16	15	15	15	15
#100 (0.15)	9	10	9	10	10
#200(0.075)	5.5	6.7	6.3	7.0	6.4
Asphalt Content, %	5.18	4.98	5.14	4.89	5.03
No. of JMFs	44	41	23	46	155*
*1 JMF could not be assigned to a region					

The standard deviation of the percent passing each sieve, and the asphalt content of the extracted RAP gradations were also computed and are shown in Table 7-13 by region. Statewide, the largest variabilities are on the 1/2" (12.5 mm) to the No. 16 (1.18 mm) sieves. Although small differences in the gradation exist between regions, the NW region of the state has the largest variability among extracted RAP gradations.

Table 7-13 Extracted RAP Gradations from Historical JMFs, Standard Deviation of Percent Passing

	NE	NW	SE	SW	Statewide
Sieve Size (mm)	Standard Deviation of % Passing				
2" (50.8)	0.00	0.00	0.00	0.00	0.00
1-1/2" (38.1)	0.00	0.00	0.00	0.00	0.00
1" (25.4)	0.19	0.19	0.00	0.00	0.14
3/4" (19)	1.41	2.09	0.67	1.28	1.57
1/2" (12.5)	3.61	7.77	1.58	5.61	5.78
3/8" (9.5)	5.20	11.98	2.64	7.93	8.42
#4 (4.75)	4.90	12.64	5.26	7.34	8.41
#8 (2.36)	4.65	9.52	6.72	5.71	6.91
#16 (1.18)	3.79	6.73	3.59	4.62	5.16
#30 (0.6)	3.41	4.82	2.23	3.56	3.94
#50 (0.3)	2.64	3.06	1.54	2.94	2.71
#100 (0.15)	1.62	2.12	1.64	2.38	2.07
#200(0.075)	0.91	1.45	1.66	1.87	1.62
Asphalt Content, %	0.42	0.61	0.38	0.44	0.49
No. of JMFs	44	41	23	46	155*
*1 JMF could not be assigned to a region					

7.2.1 Comparing RAP gradations to Typical Gradations for Chip Seals and Microsurfacing

The ODOT gradations for chip seal and microsurfacing were compared and appear to be complementary with the chip seal gradation requiring a coarser, more-uniform aggregate gradation while the microsurfacing requires finer materials. Creating a chip seal aggregate from RAP will create left-over fine RAP material that may satisfy the microsurfacing gradation requirements. The combination of using RAP for chip seal and microsurfacing could help utilize the entire RAP gradation and create a valuable use for RAP fine materials.

The RAP gradation summary from the initial 54 Ohio JMFs were compared to ODOT chip seal gradations and microsurfacing gradation bands. As noted previously many local agencies use ODOT's 2002 CMS chip gradation, which is identical to AASHTO No. 8 sized stone, except for ODOT's requirement of no more than 2% passing the No. 200 (0.075 mm) sieve. Figure 7-2 shows the 2002 ODOT CMS chip seal gradation and Figure 7-3 shows the current ODOT (2019) CMS chip seal gradations plotted over the box plots of the extracted RAP gradations. As RAP is currently processed for asphalt concrete, it will not meet ODOT 2002 CMS or ODOT 2019 CMS chip seal gradations. As such, the uniform nature of the chip seal gradations will require RAP processing.

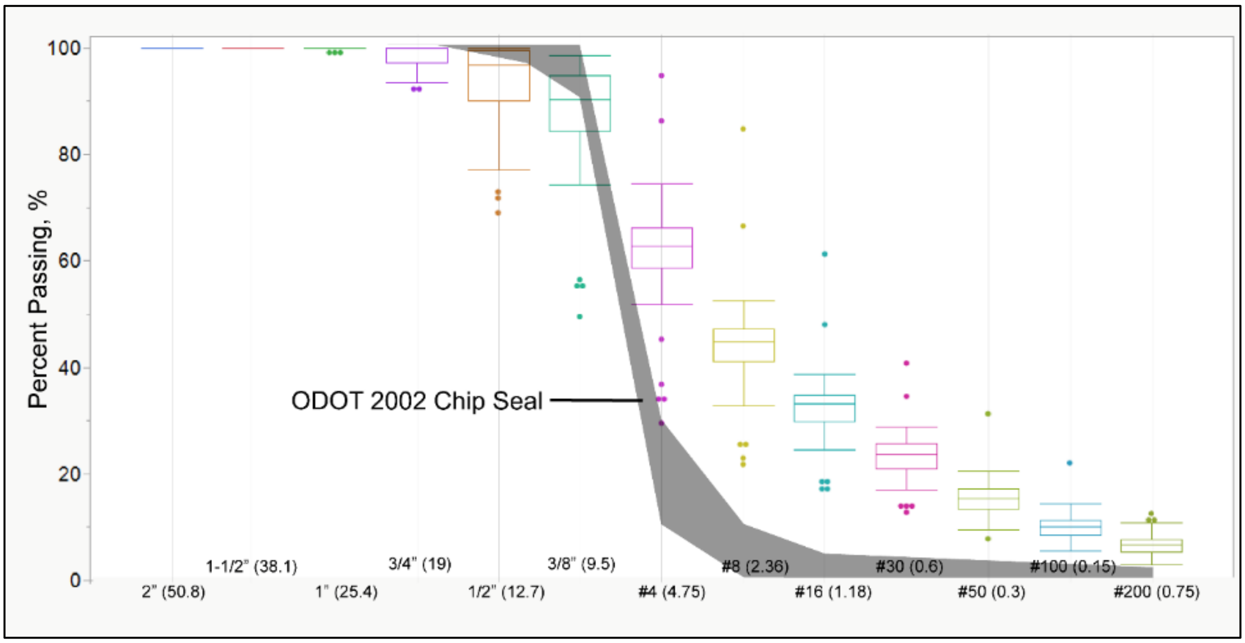


Figure 7-2 Comparison between Extracted RAP gradation and 2002 ODOT CMS Chip Seal Gradation

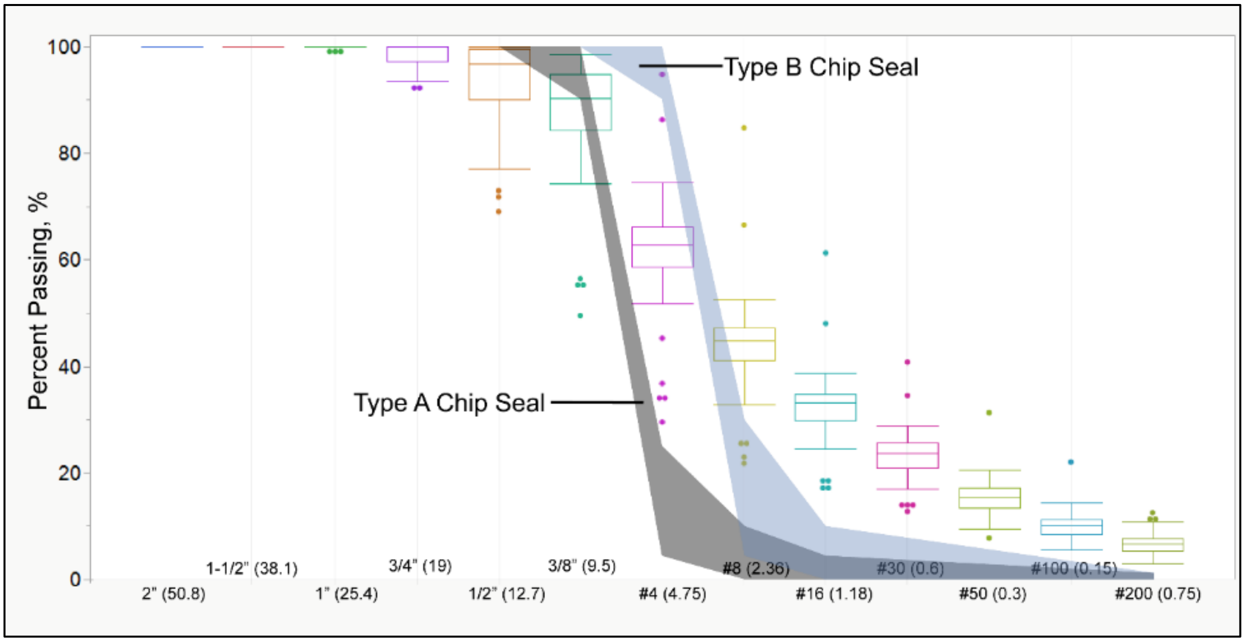


Figure 7-3 Comparison between Extracted RAP gradation and ODOT 2019 CMS Type A and Type B Chip Seal Gradations

The RAP gradations were also compared with microsurfacing gradations. ODOT 2019 CMS microsurfacing gradations were compared with the extracted RAP gradations from the initial 54 JMFs, as shown in Figure 7-4. Current extracted RAP gradations do not meet either ODOT 2019 CMS Type A or Type B microsurfacing gradations. As was the case with the chip seal gradations, additional processing of the RAP stockpile would be necessary to meet either chip seal or microsurfacing gradation bands based on ODOT gradation requirements. However, there the RAP stockpile could likely be processed into chip seal material while simultaneously producing gradations favorable to microsurfacing gradations.

It should be kept in mind the RAP gradations shown in Figures 7-2 through 7-4 are based on extracted RAP gradations, while ODOT CMS gradation requirements are based on unextracted, washed gradations. Some differences may exist between extracted RAP and unextracted RAP.

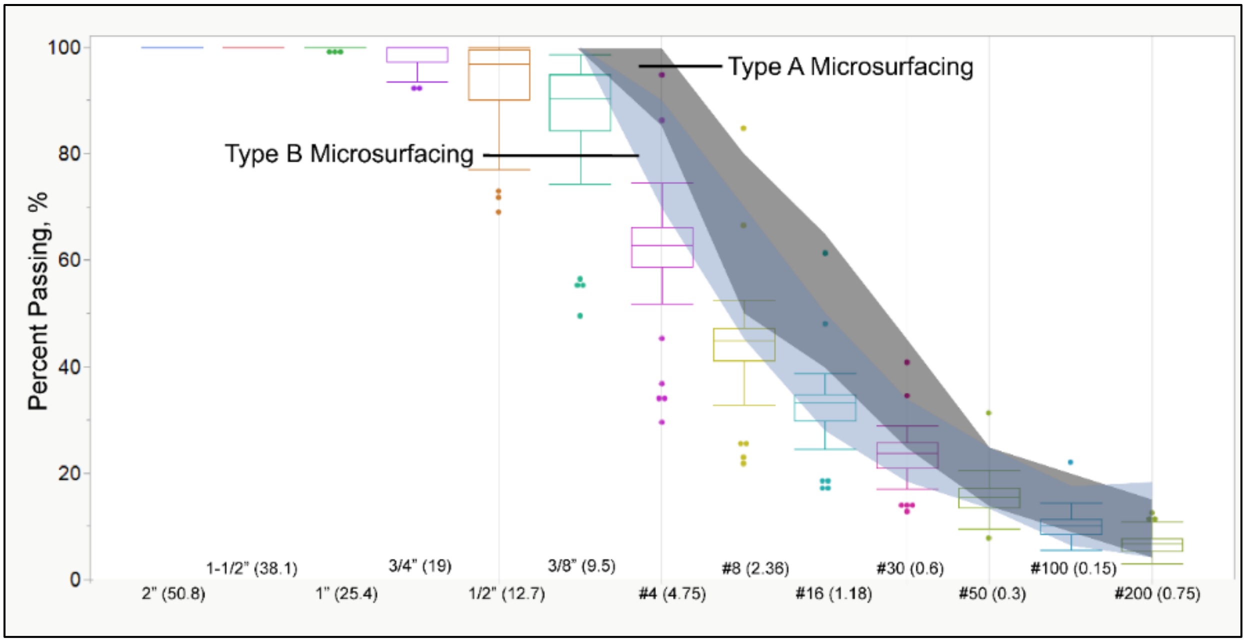


Figure 7-4 Comparison between Extracted RAP gradation and ODOT 2019 CMS Type A and Type B Microsurfacing Gradations

7.3 Laboratory Test Plan

Based on the review of existing specifications related to RAP used as an alternative to virgin aggregate and in chip seal and microsurfacing, an initial list of tests was developed for evaluating RAP for use in chip seal and microsurfacing, as shown in Table 7-14. While there are various requirements for virgin aggregate for use in chip seal and microsurfacing as identified in ODOT specifications and ISSA guidelines for chip seals and microsurfacing, focus was placed on tests specific to RAP. Specifications and recommended requirements for virgin aggregate as presented in sections 7.1.2 and 7.1.4 can be used for relative comparisons and as a reference point for putting test results of RAP in context.

Table 7-14 List of Tests Identified for Characterizing RAP for Chip Seal and Microsurfacing Treatments

Treatment	Test	Agency	Requirement
Chip Seal	Sieve analysis	See Section 7.1	See Section 7.1
	Sand equivalence	LA County*	80 min
	LA Abrasion	LA County	45%, max
Microsurfacing	Asphalt Content of RAP	LA County*	6.5%, min.
	Durability	LA County*	55%, min.
	LA Abrasion (RAP Retained on No. 4 sieve)	LA County*	35%, max.
	Sand Equivalence	LA County*	60, min.
	Soundness (5 cycles)	LA County*	15.0%, maximum

*As reported in Duncan et al., 2020

Sodium soundness is a test of aggregate durability due to weathering. Chesner et al., (1998) states the properties and quality of RAP are largely dependent on the properties and sources of the constituent materials and asphalt concrete type used in the old pavement. As such, the soundness of the RAP will be largely dependent on the soundness of the aggregate used in the pavement from which the RAP was sourced. As part of ODOT (2019) Item 703.04 and 703.05, asphalt concrete surface, intermediate, and base courses are required to meet a minimum requirement for sodium sulfate soundness test. Based on past research projects and interviews conducted with local agencies, it was found many local agencies refer to ODOT construction and materials specifications. Therefore, the research team reached out to the two agencies, Wayne County and City of Lancaster, in which test sections may be constructed using RAP as an alternative to virgin aggregate for chip seal and microsurfacing to inquire as to whether the aggregate used in their asphalt concrete pavements meet ODOT aggregate requirements. Both agencies indicated they typically require aggregate sourced from an ODOT approved supplier for their asphalt concrete. The city of Lancaster indicated the RAP planned for use in their RAP microsurfacing treatment was milled from a U.S. route in Lancaster and therefore, would have utilized aggregate meeting ODOT requirements. Additionally, one of the asphalt producers which were interviewed as part of Task 1 indicated they had run soundness tests on RAP on numerous occasions and found results consistently met ODOT requirements for virgin aggregate. Based on this information, sodium soundness was not considered to be a critical property for RAP in Ohio and was therefore, removed from the test plan.

RAP was sampled from various asphalt producers across the state. ODOT District 3 sample RAP for use in this study from 21 asphalt plants and in some cases multiple RAP piles at a plant. ODOT provided assistance in obtaining RAP from three plants in each of the other 3 regions of the state, northwest (NW), southeast (SE), and southwest (SW), as shown in Table 7-15. Although it was provided some RAP piles had been processed, for the most part the amount (or type) of processing, if any, on each pile was unknown.

Table 7-15 RAP Sources

Region	ODOT District	No. of RAP Sources	Notes
NE	3	21+	In at least one case multiple RAP piles sampled at same plant
NW	2	3	
SE	6	1	
SE	9	1	
SE	10	1	
SW	6	1	
SW	7	1	
SW	8	1	

Five RAP sources from the NE region were selected randomly for sieve analysis in addition to the 9 RAP sources from the remainder of the state to characterize the gradation of RAP across the state. Sieve analyses were conducted following AASHTO T 27 (unwashed) for these 14 RAP sources. Results were compared with various RAP gradation requirements identified in Section 7.1 and documented in the following section. Based on the results it was clear further processing would be required to achieve gradations meeting requirements for RAP as an alternative to virgin aggregate in either chip seal or microsurfacing. Many of the tests selected need to be conducted on samples representative of the chip seal or microsurfacing gradation. Therefore, each of the 14 RAP sources would need to be processed in the lab, including fractionating by sieve size and large particles crushed, if needed, then the sample reassembled to achieve a desired gradation. This is a lengthy process, and it is not feasible to process the RAP, batch the gradations, and conduct all of the tests in the test plan for all 14 RAP sources. Therefore, the remainder of the testing was focused on the RAP sources for which a chip seal and microsurfacing design would be completed in Task 7 of the project.

Wayne County was identified as the test site for test sections featuring RAP as an alternative to virgin aggregate in chip seal, and a control chip seal constructed with virgin aggregate. The City of Lancaster was identified as the location of a microsurfacing test section using RAP as an alternative to virgin aggregate and a control test section of microsurfacing with virgin aggregate. In addition to the RAP which would be used in each treatment, samples of the virgin aggregate for each treatment type were also sampled. It should be noted the virgin aggregates obtained from each Wayne County and City of Lancaster are from the aggregate source each plans to use for the control test sections. However, due to the timing of when samples were obtained (fall/winter when aggregate quarries are shut down or not producing chip seal and microsurfacing aggregate), the material was sampled from each agency's yard and were from material that remained from previous years. Therefore, the material may not be the same material used for construction of the test sections, although it will closely resemble the material placed.

A test plan was developed to evaluate RAP to be used in the design of construction of a chip seal and microsurfacing treatment, as shown in Table 7-16. In addition to testing required by agency specifications, additional tests were identified to determine material properties needed for mix design. For chip seal, the additional properties sought through lab testing for use in mix design include loose unit weight, flakiness index, and specific gravity. One practitioner indicated during the phone interviews, as noted in the literature review of this report, the parent rock of the RAP is important and if the aggregate is soft the shot rate may need to be adjusted down. Therefore, LA Abrasion was included in the test plan for RAP chip seal. Determination of asphalt content (extraction) was also included in the test plan for RAP to be used as an alternative to virgin aggregate in chip seal to quantify the amount of asphalt binder in the RAP. For microsurfacing, Methylene Blue Value was included for the RAP material and virgin aggregate to characterize the reactivity of each material for use in the mix design process.

Table 7-16 Laboratory Test Plan for Evaluating RAP for use in Chip Seal and Microsurfacing

Treatment/RAP source	Test	Specification
Chip Seal: RAP (Wayne Co.)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed) ODOT S 1039 (Extracted aggregate)
	Sand Equivalence	AASHTO T 176
	Loose Unit Weight	AASHTO T 19
	Flakiness Index	Tex-224-F and MN Seal Coat Handbook (Wood et al., 2006)
	Specific Gravity of Fine Aggregate	AASHTO T 84/ ODOT S 1031
	Specific Gravity of Coarse Aggregate	AASHTO T 85
	LA Abrasion	AASHTO T 96/ ASTM C 131
	Extraction of Asphalt Binder	AASHTO T 164
Chip Seal: Virgin Aggregate (Wayne Co.)	Sieve Analysis	AASHTO T 27 (unwashed) and AASHTO T 11 (washed)
	Sand Equivalence	AASHTO T 176
	Loose Unit Weight	AASHTO T 19
	Flakiness Index	Tex-224-F and MN Seal Coat Handbook (Wood et al., 2006)
	Specific Gravity of Fine Aggregate	AASHTO T 84
	Specific Gravity of Coarse Aggregate	AASHTO T 85
Microsurfacing: RAP (Lancaster)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed) ODOT S 1039 (Extracted aggregate)
	Sand Equivalence	AASHTO T 176
	LA Abrasion	AASHTO T 96/ ASTM C 131
	Durability Index	AASHTO T 210
	Methylene Blue Vale	ISSA TB 145
	Extraction of Asphalt Binder	AASHTO T 164
Microsurfacing: Virgin Aggregate (Lancaster)	Sieve Analysis	AASHTO T 27 (unwashed) AASHTO T 11 (washed)
	Sand Equivalence	AASHTO T 176
	Durability Index	AASHTO T 210
	Methylene Blue Vale	ISSA TB 145

While the test plan is focused on characterizing RAP, the associated virgin aggregate was subjected to the same testing to provide relative comparisons. The test plan was not intended as a verification of virgin aggregate properties relative to ODOT aggregate requirements. It should be kept in mind the application of these treatments is intended for local agencies which may or may not follow ODOT specifications. The virgin aggregate for microsurfacing in City of Lancaster was sourced from an ODOT approved supplier for microsurfacing aggregate. Due to the storage of the microsurfacing virgin aggregate at the City's yard there was some contamination of the stockpile with larger sized stone. As such, the virgin microsurfacing aggregate was sieved over a 3/8" sieve to remove large particles prior to testing. The virgin aggregate for chip seal for use in Wayne County is a No. 8 size stone and it was not sourced from a supplier that meets ODOT chip seal aggregate requirements.

Many of the tests listed in the test plan in Table 7-16 require the sample be representative of the desired chip seal or microsurfacing gradation. Therefore, target gradations for each had to be selected, and the RAP processed, fractionated and reassembled to create the selected gradation prior to testing.

7.3.1 Selection of RAP Gradations

As noted previously, RAP gradations from the 14 RAP sources sampled for this study indicated additional RAP processing would be required to meet any of the gradations for unextracted RAP for use in chip seal or microsurfacing. This was also the case for Wayne County RAP and City of Lancaster RAP.

It was learned through Task 1 phone interviews City of Lancaster had planned to place RAP chip seal and RAP microsurfacing treatments in 2021. The research team was informed the City of Lancaster had been working with Asphalt Materials, an asphalt emulsion supplier and a subsidiary of Heritage Research Group. Work conducted as part of this study is independent of the work conducted by Asphalt Materials or Heritage Research Group, however the research team has communicated with them and they have supplied asphalt emulsion for the design of microsurfacing with and without RAP. Asphalt Materials provided contact information for the RAP processing company they would be working with whom also has had experience processing RAP for chip seal. The research team reached out to the RAP processing company and inquired as to which screens may be used to process RAP into chip seal and microsurfacing gradations and what gradation requirements, if any, they follow. The research team had also inquired as part of the questionnaires conducted under Task 1 with Pavement Coatings and Pavement Recycling Systems, who are in California as to how RAP is processed for chip seal and microsurfacing. Responses varied among the organizations. Further, the research team was informed by Asphalt Materials that processed gradations can vary from one RAP stockpile to the next and RAP gradation requirements are more of a guideline as there are some limitations with what can be achieved given RAP processing operations in Ohio relative to the operations in California. Gradations were supplied to the research team based on processing of an unrelated RAP source to achieve chip seal and microsurfacing gradations. This provided the team with insight into gradations that can feasibly be achieved with available RAP processing operations.

To determine target gradations, first the gradation of the stockpile was determined by conducting sieve analysis following AASHTO T 27 on a bucket of sampled material; each bucket was sampled such that it was representative of the stockpile. Once the gradation of the stockpile was determined calculations were run to determine if one or more sieves could be used to screen the material and achieve any of the required RAP gradations. This process would be similar to processing RAP in the field, with the exception that large particles would be crushed and re-screened. Various combinations were tried; however, it was found screening the RAP over a few selected sieves would not achieve any of the RAP gradation requirements. Rather, crushing larger particles and fractionating the RAP into individual sieve sizes and then reassembling, or batching a selected gradation would be necessary.

Based on responses to the questionnaire/survey issued to local agencies in Ohio on the topic of aggregate used in pavement preservation treatments, most agencies indicated they use chip seal aggregate meeting a No. 8 sized stone (presumably, AASHTO No. 8). As shown in Table 7-17, an AASHTO No. 8 stone is very similar in size to the gradation required for ODOT (2019) Item 422 Type A chip seal. Further, PennDOT gradation requirements for RAP for chip seal were also similar to AASHTO No. 8. Therefore, initial target gradations were selected with focus on the PennDOT requirements as those are specifically for RAP. Once gradations were provided to the team that showed what gradations are achievable after processing the RAP, gradations were refined slightly, taking those gradations into consideration as well as the actual gradation of the Wayne County RAP stockpile after larger particles were crushed in the laboratory using a hammer mill. Final target gradations are presented in Table 7-17 along with gradation requirements for PennDOT RAP chip seal, AASHTO No. 8 sized stone (virgin aggregate) and ODOT (2019) 422 Type A virgin chip seal aggregate. It should be noted, the requirements listed are for washed gradations, meaning all dust (percent passing the No. 200 sieve) on the particles is accounted for. However, the target gradations are established using unwashed gradations. Therefore, the target percent passing the No. 200 sieve is intentionally zero so as to ensure too much dust, which can be detrimental to the performance of a chip seal, is not introduced.

Table 7-17 Target RAP Gradation for use in Chip Seal

	% Passing			
Sieve size	Target (Unwashed)	PennDOT RAP (washed)	AASHTO No. 8*	ODOT 422 Type A* (washed)
3/4" (19 mm)	100	100	100	100
1/2" (12.5 mm)	100	100	100	100
3/8" (9.5 mm)	92	85 – 100	85 – 100	85 – 100
No. 4 (4.75 mm)	15	0 – 30	10 – 30	5 – 25
No. 8 (2.36 mm)	5	0 – 15	0 – 10	0 – 10
No. 16 (1.18 mm)	2	0 – 10	0 – 5	0 – 5
No. 200 (0.075mm)	0	0 – 1	-	0 – 1.5

*For virgin aggregates

While no agencies provided information on microsurfacing aggregate, it is understood many local agencies rely on ODOT specifications. Currently, only LA County has written specifications for microsurfacing treatments placed with RAP which included gradation of unextracted (washed) RAP and gradation of extracted RAP. These gradation requirements along with ODOT (2019) Item 421 Type A requirements for virgin aggregate are presented in Table 7-18. Initial target gradations were developed that met both LA County unextracted RAP and ODOT 421 Type A requirements (for virgin aggregate). Once gradations were provided to the team that showed what microsurfacing gradation is achievable after processing RAP, the target gradation was refined slightly, taking the processed RAP gradation into consideration as well as the actual gradation of the Lancaster RAP stockpile after larger particles were crushed in the laboratory using a hammer mill. While it is understood there are limitations with what can be achieved through RAP processing, the technical advisory committee expressed concerns about deviating from existing RAP gradation requirements, particularly where the gradation was coarser than requirements for microsurfacing treatments at the finer sieve sizes (No. 50 – No. 200) as were the gradations provided to the team. Therefore, the target gradation for RAP for use in microsurfacing was adjusted to meet minimum requirements for LA County unextracted RAP gradations on the No. 50 and No. 100 sieve. As was the case with the RAP chip seal gradation, the final target gradation, as shown in Table 7-18 is for unwashed and unextracted RAP. Therefore, the percent passing the No. 200 sieve is intentionally set lower than LA County's requirement for unextracted and washed RAP to ensure the maximum of 12% is not exceeded.

Table 7-18 Target RAP Gradation for use in Microsurfacing

Sieve size	% Passing			
	Target (Unwashed)	LA County Unextracted RAP (washed)	LA County Extracted RAP	ODOT 421 Type A* (washed)
3/8" (9.5 mm)	100	100	100	100
No. 4 (4.75 mm)	100	95 - 100	90 - 100	85 - 100
No. 8 (2.36 mm)	75	65 - 85	65 - 90	50 - 80
No. 16 (1.18 mm)	43	35 - 60	45 - 70	40 - 65
No. 30 (0.600 mm)	21	18 - 38	30 - 50	25 - 45
No. 50 (0.300 mm)	9	8 - 25	18 - 36	13 - 25
No. 100 (0.150 mm)	5	5 - 20	10 - 24	-
No. 200 (0.075mm)	1.5	2 - 12	5 - 15	5 - 15

*For virgin aggregates

Through screening and the use of a small hammer mill in the laboratory, approximately 46% to 64% of the Lancaster RAP met the target microsurfacing gradation, while 26% to 44% of the Wayne County RAP met the target chip seal gradation. Ranges depend on the amount of crushing conducted in the laboratory and may not reflect the capability of full-scale operations.

7.4 Results of Laboratory Tests

Once target gradations were determined, the fractionated RAP was reassembled, or batched to create samples as needed for each test as part of the test plan shown in Table 7-16. The results of the testing conducted on RAP and virgin aggregate from Wayne County and City of Lancaster are presented here, as well as the results of the sieve analyses on the 14 RAP stockpiles sampled across the state.

7.4.1 Gradations of RAP Stockpiles

As noted previously sieve analyses were performed on samples obtained from 14 different RAP stockpiles from across the state, representing all 4 regions of the state and 7 of the 12 ODOT districts, as shown In Table 7-19. The resulting gradations of all 14 RAP sources are presented in Figure 7-5. These gradations represent the RAP stockpile from which they were sampled and are the unwashed gradations, meaning there is likely a higher dust content (percent passing the Number 200 sieve) than shown here. There is a wide range of percent passing any given sieve. This could be related to the timing of the samples collected. Samples outside of the NE region were collected at the end of the paving season when many plants were shut down or running intermittently. During this down time asphalt plants typically prepare for the following paving season by processing the RAP recently obtained. Given the timing of sample collection, RAP stockpiles may or may not have been processed yet. While some samples labels indicated the stockpile had been processed, others had no indication. Wide ranges could also be related to the type of processing used at each plant. As shown previously with the extracted RAP gradations from the asphalt concrete JMFs, overall gradations range widely. Therefore, these results were not unexpected.

Table 7-19 Location of RAP Sources for which Sieve Analyses Were Conducted.

Region	District	Plant/RAP Source
NE	3	A
NE	3	B
NE	3	C
NE	3	D
NE	3	E
SE	10	F
SE	9	G
SW	7	H
SW	8	I
SE	6	J
NW	2	K
NW	2	L
SW	6	M
NW	2	N

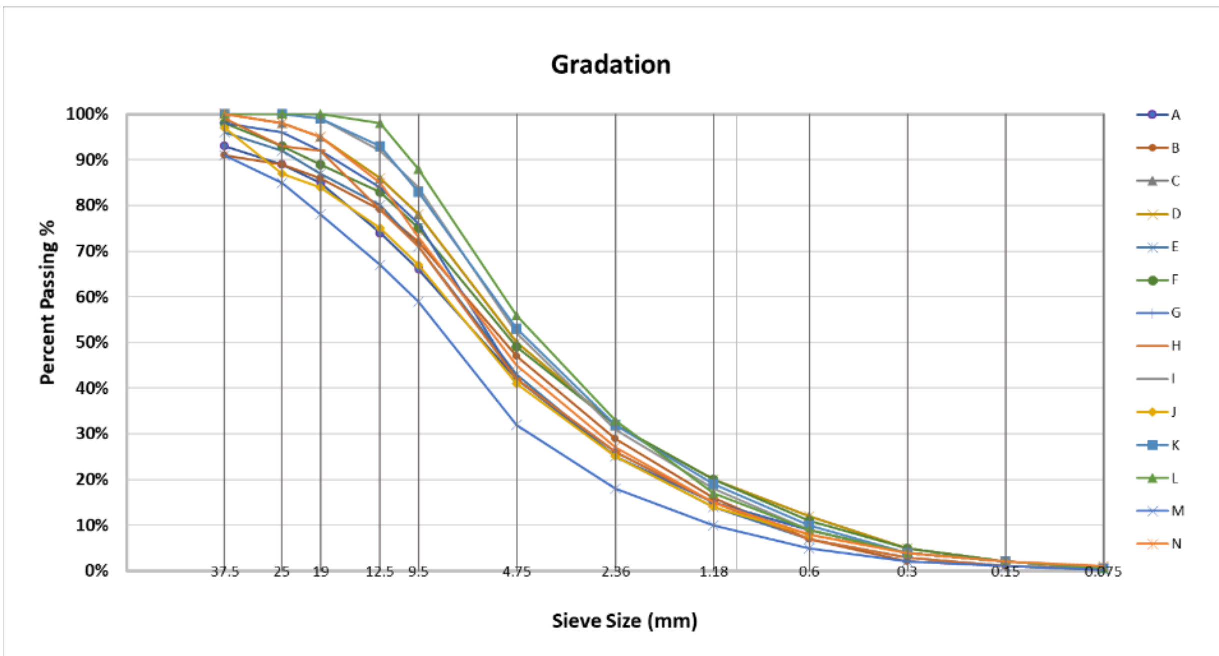


Figure 7-5 Gradation of RAP Sources from across Ohio.

Due to the large sized RAP particles, none of the 14 RAP sources meet any of the existing gradation requirements for RAP used as an alternative to virgin aggregate in chip seal or microsurfacing. Therefore, further processing would be required to use these stockpiles in chip seal and/or microsurfacing applications.

Sieve analyses following AASHTO T 27 were also conducted on representative samples obtained from RAP stockpiles in Wayne County and in the City of Lancaster which are intended to be used for the construction of a RAP chip seal and RAP microsurfacing treatment, respectively. The gradation of the Wayne County RAP is shown in Figure 7-6. For comparison, RAP gradations requirements from PennDOT, and the Green Book for

5/16" by No. 8 sized RAP, which is the most frequently placed RAP chip seal in LA County (Duncan et al., 2020). For relative comparison with commonly used requirements for virgin aggregate in Ohio, lower and upper gradation limits are also shown for ODOT (2019) 422 Type A chip seal aggregate, and AASHTO No. 8 sized stone. In comparing the gradation of the Wayne County RAP to the various gradation requirements, it is evident the stockpile is finer than the requirements from the No. 4 sieve (4.75 mm) down. This makes it difficult to meet any requirements and will likely mean portions of the stockpile cannot be used.

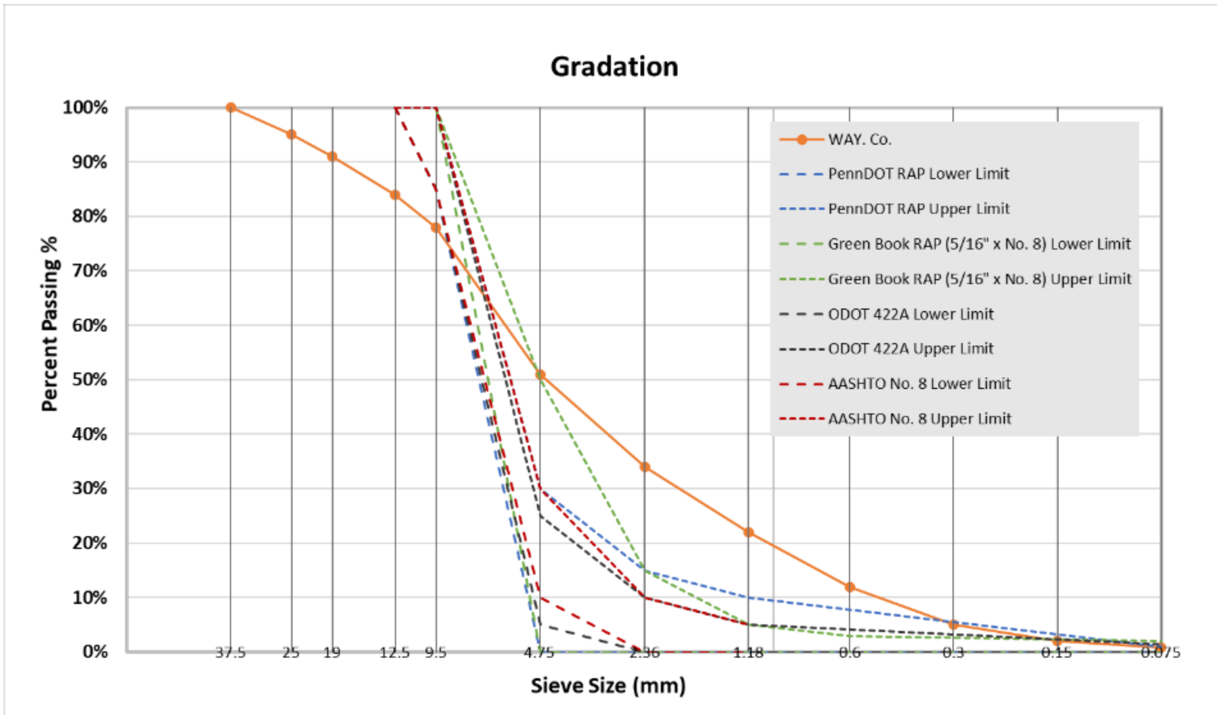


Figure 7-6 Gradation of Wayne County RAP Stockpile Relative to Various Chip Seal Gradation Requirements

The gradation of RAP from the City of Lancaster is shown in Figure 7-7. For comparison, RAP gradation requirements for unextracted and washed RAP and extracted RAP from LA County are also shown. Additionally, for relative comparison with requirements for virgin aggregate in ODOT's microsurfacing treatment, the lower and upper gradation limits are also shown for ODOT (2019) 421 Type A microsurfacing. In comparing the gradation of the RAP from the City of Lancaster to the various gradation requirements, it is evident the stockpile is much coarser than the requirements at each sieve size. This indicates substantial crushing may be necessary.

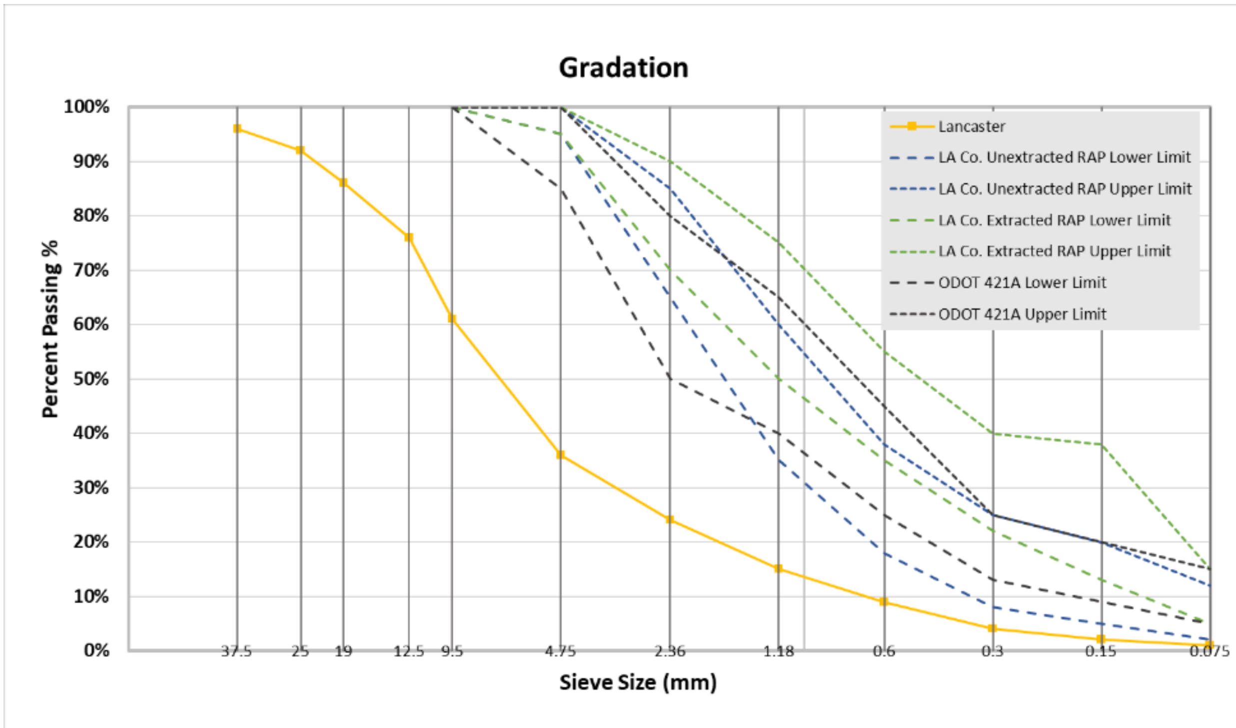


Figure 7-7 Gradation of City of Lancaster RAP Stockpile Relative to Various Microsurfacing Gradation Requirements

7.4.2 Test Results for Chip Seal Aggregate

As noted previously, the Wayne County RAP was crushed and fractionated in the laboratory. Prior to conducting the tests listed in Table 7-16 samples were prepared using the individual fractions to meet the requirement of the test, which in some cases entailed batching the samples to meet target gradations as shown in Table 7-17.

Results for the washed gradation following AASHTO T 11 and the extracted RAP gradation following AASHTO T 164 and ODOT S 1039 are presented in Table 7-20. For comparison the requirements for RAP gradation meeting PennDOT specifications and for virgin aggregate meeting AASHTO No. 8 are also presented in the table. Washed gradations fall within the gradation bands for PennDOT RAP requirements and requirements for AASHTO No. 8, although the percent passing the No. 200 sieve was just outside (finer than) the ODOT (2019) 422 Type A gradation requirement. The extracted RAP aggregate is much finer than either PennDOT or AASHTO No. 8 requirements. Large differences between the percent passing for unextracted washed RAP gradations and extracted RAP gradations were observed, however, large differences were also noted in Duncan et al. (2020) for RAP graded for microsurfacing. The authors stated this is an indication of significant adhesion and conglomeration of fine aggregates. The asphalt content of the Wayne County RAP at the target gradation was found to be 3.5%, however there is no requirement for comparison for RAP used in chip seal treatments.

Table 7-20 Washed and Extracted Gradation of Wayne County RAP for use in Chip Seal

Sieve size	Wayne Co. RAP Chip			PennDOT RAP Requirement	AASHTO No. 8 (virgin aggregate)
	% Passing			% Passing	% Passing
	Unextracted (Unwashed)	Unextracted (Washed)	Extracted	Washed	
3/4" (19 mm)	100	100	100.0	100	100
1/2" (12.5 mm)	100	100	100	100	100
3/8" (9.5 mm)	92	92	97	85 – 100	85 – 100
No. 4 (4.75 mm)	15	15	43	0 – 30	10 – 30
No. 8 (2.36 mm)	5	5	26	0 – 15	0 – 10
No. 16 (1.18 mm)	2	2	20	0 – 10	0 – 5
No. 200 (0.075mm)	0	1.9	3.8	0 – 1	
Asphalt Content			3.5%		

The results of the unwashed and washed sieve analysis of the virgin aggregate from Wayne County, a No. 8 sized limestone, are presented in Table 7-21. The virgin aggregate does not meet the AASHTO No. 8 gradation requirements at the ½” (12.5 mm), and 3/8” (9.5 mm) sieve size. The washed RAP gradation is comparable to the virgin aggregate gradation except at the 3/8” sieve in which the virgin chip seal aggregate is coarser than the RAP chip.

Table 7-21 Results of Sieve Analysis on No. 8 Chip Seal Aggregate from Wayne County

	Wayne Co. Virgin Aggregate, No. 8 Limestone		AASHTO No. 8 Requirements
	% Passing		% Passing
Sieve size	Unwashed	Washed	
3/4" (19 mm)	100	100	100
1/2" (12.5 mm)	99	99	100
3/8" (9.5 mm)	63	63	85 – 100
No. 4 (4.75 mm)	11	11	10 – 30
No. 8 (2.36 mm)	3	3	0 – 10
No. 16 (1.18 mm)	2	2	0 – 5
No. 200 (0.075mm)	1.3	3.6	

Sand equivalence was determined for both Wayne County RAP and Wayne County virgin chip seal aggregate following AASHTO T 176. Results for both RAP and virgin chip seal aggregate are presented in Table 7-22. As shown in the table, the minimum sand equivalence value specified by LA County for RAP chip seal aggregate is 80%. The Wayne County RAP easily meets this minimum value.

Table 7-22 Results of Sand Equivalence Tests

	Wayne Co. RAP Chip				LA County RAP Requirement	Wayne Co. Virgin Chip Seal Aggregate		
Reading	1	2	3	4	80%, Minimum	1	2	3
Sand Equivalence (SE)	96%	98%	100%	100%		87%	84%	87%
Average SE	99%					86%		

The loose unit weight, determined by AASHTO T 19, of the Wayne County RAP graded for chip seal are presented along with the loose unit weight of the virgin chip seal aggregate from Wayne County in Table 7-23. There are no requirements associated with this property, however, it is useful for developing the chip seal mix design.

Table 7-23 Loose Unit Weight of Wayne County RAP for Chip Seal and Wayne County Virgin Chip Seal Aggregate

Material	Loose unit weight	
	lb/ft^3	g/cm^3
Wayne Co. Chip Seal RAP	85	1.355
Wayne Co. Virgin Chip Seal Aggregate	96	1.530

Flakiness Index is another property for which requirements do not exist for virgin chip seal aggregate, or RAP chips, although it is a useful property for chip seal mix design. The Flakiness Index was determined following the Tex-224-F procedure and gauge size as described in the Minnesota Seal Coat Handbook (Wood et al., 2006). The Flakiness Index is calculated using the equation shown below. Results for the virgin chip seal aggregate and RAP from Wayne County are provided in Table 7-24. As shown in the table, both virgin aggregate and RAP are less than 25% as recommended in the Minnesota Seal Coat Handbook (Wood et al., 2006) for virgin aggregate.

$$Flakiness\ Index = \frac{Total\ Passing\ Slots}{Total\ Passing\ Slots + Total\ Retain\ on\ Slots}$$

Table 7-24 Flakiness Index Results for RAP Chips and Virgin Chip Seal Aggregate

Size fraction	Wayne Co. RAP Chip			Wayne Co. Virgin Chip Seal Aggregate		
	Weight retained on slot (g)	Weight passing slot (g)	Sum (g)	Weight retained on slot (g)	Weight passing slot (g)	Sum (g)
1 in to 3/4	0	0	0.0	0	0	0.0
3/4 in to 1/2	0	0	0.0	2.5	6	8.5
1/2 in to 3/8 in	44	4	48.0	304	37	341.0
3/8 in to 1/4 in	260.5	30.5	291.0	420	41	461.0
1/4 in to No. 4	139.5	22.5	162.0	133	19.5	152.5
Total	444	57	501.0	859.5	103.5	963.0
Flakiness Index	11.38%			10.75%		

The bulk specific gravity, bulk saturated surface dry (SSD) specific gravity, apparent specific gravity and absorption of coarse and fine RAP chips and virgin aggregate were determined following AASHTO T 85 and AASHTO T 84, respectively. The results are tabulated in Table 7-25. There are no requirements virgin or RAP chips associated with these tests, however, the values may be used in the mix design process.

Table 7-25 Specific Gravity of Coarse and Fine Chip Seal Aggregate

Material	Bulk Specific Gravity (SG)	Bulk SSD SG	Apparent SG	Absorption %
Coarse Aggregate: Wayne County RAP Chip	2.441	2.480	2.541	1.6
Coarse Aggregate: Wayne County Virgin Chip	2.663	2.708	2.788	1.7
Fine Aggregate: Wayne County RAP Chip	2.337	2.374	2.427	1.6
Fine Aggregate: Wayne County Virgin Chip	2.550	2.613	2.722	2.5

Lastly, LA Abrasion testing following AASHTO T 96/ASTM C131 was conducted on the Wayne County RAP. Grading C was selected for testing as it most closely reflected the target gradation. A sample was prepared of approximately 2500 grams of RAP passing the 3/8” (9.5 mm) sieve and retained on the ¼” (6.3 mm) sieve and 2500 grams of RAP passing the ¼” (6.3 mm) sieve and retained on the No. 4 sieve. ODOT (2019) specifies a maximum of 40% mass loss for coarse virgin chip seal aggregate. While ISSA A165 lists a maximum of 25% for virgin chip seal aggregate (ISSA A165). LA County (LA County DPW, 2015) specifies a maximum mass loss of 45%. The mass loss by LA Abrasion test for the Wayne County RAP was 23%. Therefore, the Wayne County RAP meets both requirements for RAP and virgin chip seal aggregate.

7.4.3 Test Results for Microsurfacing Aggregate

As noted previously, City of Lancaster RAP was crushed and fractionated in the laboratory. Prior to conducting the tests listed in Table 3-3 samples were prepared using the individual fractions to meet the requirement of the test, which in some cases entailed batching the samples to meet target gradations as shown in Table 7-17.

Results for the washed gradation following AASHTO T 11 and the extracted RAP gradation following AASHTO T 164 and ODOT S 1039 for Lancaster RAP graded for microsurfacing are presented in Table 7-26. For comparison the LA County requirements for RAP unextracted and extracted gradations for microsurfacing are also presented in the table, as well as ODOT (2019) requirements for virgin aggregates in Item 421 Type A microsurfacing. Differences between extracted and unextracted percent passing are noted, with the largest differences occurring on the No. 16 sieve through the No. 100 sieve. As mentioned previously, Duncan et al. (2020) also reported large differences for RAP graded for microsurfacing and such difference may be an indication of significant adhesion and conglomeration of fine aggregates. In comparing the unextracted (washed) and extracted gradations for the Lancaster RAP with LA County RAP requirements, all gradation requirements are met with the target gradation. Additionally, the minimum asphalt content of 6.5% is also met, as the Lancaster RAP graded for microsurfacing contained 7.2% asphalt.

Table 7-26 Washed and Extracted Gradation of City of Lancaster RAP for use in Microsurfacing

	Lancaster RAP for Microsurfacing			LA County RAP for Microsurfacing		ODOT 421 Type A*
	Unextracted (Unwashed)	Unextracted (Washed)	Extracted	Unextracted (Washed)	Extracted	(Washed)
Sieve size	% Passing			% Passing		% Passing
3/8" (9.5 mm)	100	100	100	100	100	100
No. 4 (4.75 mm)	100	100	99	95 - 100	90 - 100	85 - 100
No. 8 (2.36 mm)	75	75	81	65 - 85	65 - 90	50 - 80
No. 16 (1.18 mm)	43	43	56	35 - 60	45 - 70	40 - 65
No. 30 (0.600 mm)	21	21	39	18 - 38	30 - 50	25 - 45
No. 50 (0.300 mm)	9	9	24	8 - 25	18 - 36	13 - 25
No. 100 (0.150 mm)	5	5	18	5 - 20	10 - 24	-
No. 200 (0.075mm)	1.5	4.7	11.4	2 - 12	5 - 15	5 – 15
Asphalt Content			7.2%		6.5%, min	

The results of the unwashed and washed sieve analysis of the virgin microsurfacing aggregate from City of Lancaster are presented in Table 7-27. The virgin aggregate had a small percentage of material coarser than the 3/8" (9.5 mm) sieve despite efforts to remove contaminants. Based on findings reported by Duncan et al. (2020) differences between the virgin aggregate gradation and unextracted and extracted RAP gradations were expected. This was the case here, as the percent passing each sieve was greater for the extracted RAP than the virgin aggregate.

Table 7-27 Virgin Microsurfacing Aggregate Gradations, City of Lancaster

	Lancaster virgin microsurfacing aggregate		ODOT 421 Type A
	(Unwashed)	(Washed)	(Washed)
Sieve size	% Passing		% Passing
3/4" (19 mm)	100	100	
1/2" (12.5 mm)	98	98	
3/8" (9.5 mm)	97	97	100
No. 4 (4.75 mm)	93	93	85 - 100
No. 8 (2.36 mm)	67	67	50 - 80
No. 16 (1.18 mm)	42	42	40 - 65
No. 30 (0.600 mm)	27	27	25 - 45
No. 50 (0.300 mm)	17	17	13 - 25
No. 100 (0.150 mm)	11	11	-
No. 200 (0.075mm)	7.2	10.7	5 – 15

Sand equivalence was determined for Lancaster RAP graded for microsurfacing and Lancaster's virgin microsurfacing aggregate following AASHTO T 176. Results for both are presented in Table 7-28. As shown in the table, the minimum sand equivalence value specified by LA County for RAP microsurfacing aggregate is 60% following ASTM D2419, which is very similar to AASHTO T 176. The Lancaster RAP easily meets this minimum value.

Table 7-28 Results of Sand Equivalence Tests

	Lancaster RAP for Microsurfacing				LA County RAP Requirement	Lancaster Virgin Microsurfacing Aggregate			
Reading	1	2	3	4	60%, Minimum	1	2	3	4
Sand Equivalence (SE)	90%	89%	87%	89%		76%	76%	83%	73%
Average SE	89%					77%			

LA Abrasion testing following AASHTO T 96/ASTM C131 was conducted on the RAP from the City of Lancaster. While the LA County requirements are for RAP retained on the No. 4 sieve, in the gradation selected, 100% of the RAP passes the No. 4 sieve. Further limited material was available at this fraction due to crushing that was required to obtain the individual fractions and batch the material to meet the selected gradation. Therefore, grading D, which consists of approximately 5000 grams of RAP passing the No. 4 sieve and retained on the No. 8 sieve, was selected for testing as it more closely reflected the target gradation. The mass loss by LA Abrasion test for the Lancaster RAP was found to be 23%, which meets LA County's maximum requirement of 35%. In comparing the mass loss by LA Abrasion test for Lancaster RAP to requirements for virgin microsurfacing aggregate, the Lancaster RAP would pass both ODOT and ISSA requirements as well. ODOT (2019) specifies a maximum of 40% mass loss for coarse virgin microsurfacing aggregate. While ISSA A143 lists a maximum of 30% for virgin microsurfacing aggregate.

Durability index was determined for Lancaster RAP and Lancaster virgin microsurfacing aggregate following AASHTO T 210. The durability index indicates the relative resistance of an aggregate to produce claylike fines under mechanical degradation (AASHTO T 210). LA County requires RAP used for microsurfacing have a minimum durability index of 55%, following CTM 229, which is based on the AASHTO T 210 procedure. Results for Lancaster RAP and Lancaster virgin microsurfacing aggregate are provided in Table 7-29. The Lancaster RAP easily met the LA County requirement for RAP.

Table 7-29 Durability Index for Lancaster RAP and Lancaster Virgin Microsurfacing Aggregate

	Lancaster RAP for Microsurfacing				LA County RAP Requirement	Lancaster Virgin Microsurfacing Aggregate		
Reading	1	2	3	4	55%, Minimum	1	2	3
Durability Index	71%	75%	71%	73%		96%	100%	98%
Average Durability Index	72%					98%		

Lastly, methylene blue value (MBV) was determined for the Lancaster RAP and virgin microsurfacing aggregate following ISSA TB 145. Results are presented in Table 7-30. While no criteria are established for MBV, it does provide insight into the reactivity of the RAP and virgin aggregate which may be useful during the mix design process.

Table 7-30 MBV Results for RAP and Virgin Microsurfacing Aggregate, City of Lancaster

	RAP for Microsurfacing	Virgin Microsurfacing Aggregate
MBV	6.0 mg/g, 0/No. 200 (0.075 mm)	2.5 mg/g, 0/No. 200 (0.075mm)

7.5 *Tool to Assess Usability of RAP Stockpile*

A Visual Basic code was developed for EXCEL to assess the percent of the RAP stockpile that can be used based on a desired gradation for chip seal and/or microsurfacing treatments. The tool allows the user to enter the RAP stockpile gradation and a user-defined target gradation. The tool evaluates the percent of the stockpile that can be used. The tool also allows the user to enter gradations based on trial crushing operations to determine the impact had on the percent of the stockpile that can be used based on the target gradations. Additionally, the tool can be used to maximize the usage of a stockpile, by looking at up to 6 different target gradations. This allows for the user to assess whether the stockpile can be used for both chip seal and microsurfacing treatments, and the target gradations needed to maximize use of the stockpile. Shown in Figure 7-8 is a beta version of the tool.

Figure 7-8 Tool to Assess Usability of RAP Stockpile

7.6 *Summary of Findings*

Agency specifications relative to the use of RAP in chip seal or microsurfacing applications were identified and reviewed. RAP gradation requirements were identified for chip seal treatments for three agencies, while only one agency has requirements for microsurfacing. Sieve analyses were performed on samples obtained from 14 RAP stockpiles across the state. Further testing was conducted on RAP from Wayne County and RAP from the City of Lancaster which will be used for mix design testing and construction of RAP chip seal and RAP microsurfacing applications, respectively.

Prior to carrying out the test plan on the two RAP sources (Wayne County and City of Lancaster), target gradations were selected. RAP samples were then produced in the lab by fractionating the material at each sieve size and batching samples to meet the target gradations. For RAP chip seal, target gradations were selected that met PennDOT RAP gradation requirements as well as AASHTO No. 8 sized stone as the PennDOT requirements were similar to AASHTO No. 8. Based on survey responses from Task 3 it was found most local agencies use virgin aggregate that meet AASHTO No. 8, therefore, the research team chose target RAP gradations that were similar, as agencies may be more comfortable working with a material that resembles the virgin aggregate they are used to working with. For microsurfacing, the research team selected target RAP gradations that met LA County unextracted RAP gradations. All target gradations were based on unwashed gradations. Therefore, washed gradations were determined following AASHTO T 11 for comparison with the RAP gradation requirements which included percent passing the No. 200 sieve when washed.

Testing was conducted in the laboratory for comparisons with established requirements for RAP for use in chip seal or microsurfacing. Testing was also conducted to determine RAP properties that may be useful in mix design tests. Results compared with the identified requirements are summarized in Table 7-31. Although it is not shown in the table, washed gradations were met for each chip seal and microsurfacing. Furthermore, LA County extracted gradation requirements were also met for RAP in microsurfacing. As shown all RAP requirements were met for chip seal using Wayne County RAP and likewise, all RAP requirements for microsurfacing were met using Lancaster RAP. Furthermore, where ISSA or ODOT requirements exist for virgin aggregate for the same tests listed in Table 7-31, the tested RAP met or exceeded such requirements. Thus, the use of RAP in chip seal or microsurfacing applications should be feasible, however, additional testing should be conducted to determine if the RAP sources can meet mix design requirements for each application.

Table 7-31 Summary of Test Results for RAP Relative to RAP Requirements

Treatment/ Material	Test	Agency	Requirement	Test Result
Chip Seal: Wayne Co. RAP	Sieve analysis	PennDOT	Table 7-2	Table 7-2
	Sand equivalence	LA County	80 min	99
Microsurfacing: Lancaster RAP	Sieve Analysis	LA County	Table 7-8	Table 7-8
	Asphalt Content of RAP	LA County	6.5%, min.	7.2%
	Durability	LA County	55%, min.	72%
	LA Abrasion (RAP Retained on No. 4 sieve)	LA County	35%, max.	23%
	Sand Equivalence	LA County	60, min.	89

8 Design of Chip Seal Mixes

The objective of Task 7 was to develop mix designs based on the findings presented in Section 7, Characterization of RAP for use in Microsurfacing and Chip Seals on Local Roadways. As described in Section 5, this research focused on RAP stockpiled by two local agencies: Wayne County and the City of Lancaster. The findings from Task 6 indicated RAP from Wayne County is suitable as an alternative to virgin aggregate in chip seal and RAP from the City of Lancaster is suitable as an alternative to virgin aggregate in microsurfacing. Because the properties of RAP and virgin aggregate are discussed previously under Section 7, this section is focused on the methodologies used in mix design of RAP chip seal using RAP from Wayne County.

In Wayne County, four test sections are proposed on Chippewa Road, each 1,000 feet in length. Two, one in each lane, are planned at the first 1,000 feet north of the intersection with Smucker Road. The other two sections are proposed at the first 1,000 feet south of the intersection, such that there is one section in each lane. Based on existing pavement conditions, the virgin chip seal mix will be applied to the northbound lanes both north and south of the Smucker intersection, and the RAP chip seal mix will be applied to the Southbound lanes both north and south of the Smucker intersection.

Based on the preferred preservation treatment, and the respective material characteristics from each location, appropriate mix designs were developed. Table 8-1 provides an overview of the chip seal mix designs developed for this study.

Table 8-1 Overview of Chip Seal Mix Designs

Agency	Treatment	Road Name	Direction	Location	Length (feet)	Mix type
Wayne County	Chip Seal	Chippewa	NB	North of Smucker	1000	Virgin Mix 1
Wayne County	Chip Seal	Chippewa	NB	South of Smucker	1000	Virgin Mix 2
Wayne County	Chip Seal	Chippewa	SB	North of Smucker	1000	Rap Mix 1
Wayne County	Chip Seal	Chippewa	SB	South of Smucker	1000	Rap Mix 2

There are two common methods for chip seal design, including the McLeod method and the New Zealand method. The McLeod method focuses on a purely voids approach, where the primary objective is to calculate the void space in the aggregate and fill a certain amount of that space with binder. In contrast, the New Zealand method considers substantially more characteristics of the pavement to make a recommendation on aggregate and binder application rates. Because chip seal mix design is an art and not an exact science, both of these methods are evaluated. At the end of this section, the ranges provided by these two approaches and final recommended mixes are provided. Due to the nature of chip seal, field adjustments are expected. Therefore, the selection of the precise application rates will be determined based on field conditions and crew experience at the time of placement. Tables and figures are provided to aid in these field adjustments.

8.1 McLeod design methodology overview

The McLeod design procedure focuses on ensuring an appropriate amount of void space is filled with binder. This method uses the aggregate gradation, shape and specific gravity for the aggregate application rate, while traffic information, pavement condition and aggregate absorption and shape determine the binder application rate. The McLeod design procedure is based on two principles: (1) the resulting seal coat will be one stone size thick with the aggregate application rate being independent of the pavement condition and binder type, and (2) the voids in the aggregate layer need to be 70% filled with asphalt binder for good performance.

8.1.1 Average least dimension and flakiness index

The shape of the aggregate particles play an important role in determining the chip application rate. The flakiness index, or the percent (by weight) of flat particles, determines the average least dimension (*ALD*) of the aggregate and thus influences the chip seal design. The ALD is calculated as follows:

$$ALD = \frac{M}{1.1139285 + 0.011506F}$$

where,

ALD is the average least dimension (inches),
M is the median particle size (inches), and
F is the flakiness index (percent).

The variables used in this equation, and *ALD* for the virgin and RAP chip seal mixes are presented later in this report, in Table 8-7.

8.1.2 Voids in loose cover aggregate

The loose unit weight of the aggregates (*W*), as determined by AASHTO T 19, indicates the amount of air voids expected between the aggregate in a loose condition. The amount of air voids expected between the chips when dropped from the spreader is then referred to as the voids in loose aggregate (*V*).

$$V = 1 - \frac{W}{62.4G}$$

where,

V is the voids in loose aggregate (in percent, expressed as a decimal),
W is the loose unit weight of the aggregates (lbs/ft^3), and
G is the bulk specific gravity of the aggregate (AASHTO T 19).

The variables used in this equation, and *V* for the virgin and RAP chip seal mixes are presented later in this report, in Table 8-7.

8.1.3 Traffic volume

The embedment of chips into the asphalt binder is dependent on the compaction caused by traffic, which is measured in vehicles per day (veh/day). Higher traffic volumes need a smaller binder application rate than lower volume roads since the weight of the vehicles compact the applied seal coat, pushing the aggregate into the binder and decreasing the air voids. Without sufficient compaction from traffic, a higher binder application rate is needed so more binder can fill the voids between the aggregate. The traffic correction factor (*T*) is based on the number of vehicles per day, as described in Table 8-2.

Table 8-2 Traffic Correction Factor, *T*

Traffic (Veh/day)	Traffic Correction Factor, *T*, (percentage, expressed as a decimal)*
Under 100	0.85
100-500	0.75
500-1000	0.70
1000-2000	0.65
Over 2000	0.60

*the percentage of the ultimate 20% void space in the aggregate to be filled with asphalt

On Chippewa Road, north of the Smucker Road intersection, traffic volumes (*AADT*) are approximately 367 veh/day. South of the intersection with Smucker Road, the *AADT* is higher, at approximate 724 veh/day. Based on these values, a traffic correction factor of 0.75 North of Smucker Road is recommended and a traffic correction factor of 0.70 south of Smucker Road is recommended. This information is summarized later in the report, in Table 8-8.

8.1.4 Whip off factor

The McLeod design also uses traffic whip off factor because some aggregate will be lost due to passing vehicles as the seal coat is curing. A traffic whip off factor (*E*) is used in determining if changes need to be made in the chip application rate. The percentage waste (*Q*) generally ranges between 5% and 10%, with lower percentage losses for low volume roads and higher percentage losses for high volume roads. The traffic whip off factor can be calculated by the following:

$$E = 1 + \frac{Q}{100}$$

where,

E is the wastage factor, and
Q is the percentage waste allowed for traffic whip-off and handling.

Because Chippewa Road has a low traffic volume, *Q* is assumed to be 5%, which leads to a wastage factor of 1.05.

8.1.5 Existing pavement condition

Existing pavement condition can have a substantial impact on aggregate embedment. In general, the drier and more porous the pavement, the more binder that is absorbed. Similarly, newer, smoother pavements with less air voids absorb less binder. Thus, binder application must be adjusted for the condition of the pavement. Table 8-3 indicates the surface correction factor for various types of pavements.

Table 8-3 Surface Correction Factor, *S*

Existing Pavement Texture	**Surface Correction Factor, *S***
Black, flushed asphalt surface	- 0.01 to 0.06
Smooth nonporous surface	0.00
Slightly porous, oxidized surface	+ 0.03
Slightly pocked, porous, oxidized surface	+ 0.06
Badly pocked, porous, oxidized surface	+ 0.09

Pavement condition testing was performed on the northbound and southbound lanes on Chippewa Road both north and south of the intersection with Smucker Road. Condition was monitored in the middle of each subsection in the centerline (CL) of each lane and in the inside wheel path (IWP) of each lane. A number 1 through 4 was assigned for pavement conditions as listed below and as shown in Figure 8-1, based on those presented in the Minnesota Seal Coat Handbook (Wood et al., 2006). Tables 8-4 and 8-4 then summarize the observed data.

1. Smooth, non-porous surface.
2. Slightly porous and oxidized surface.
3. Slightly pocked, porous and oxidized.
4. Badly pocked, porous and oxidized.

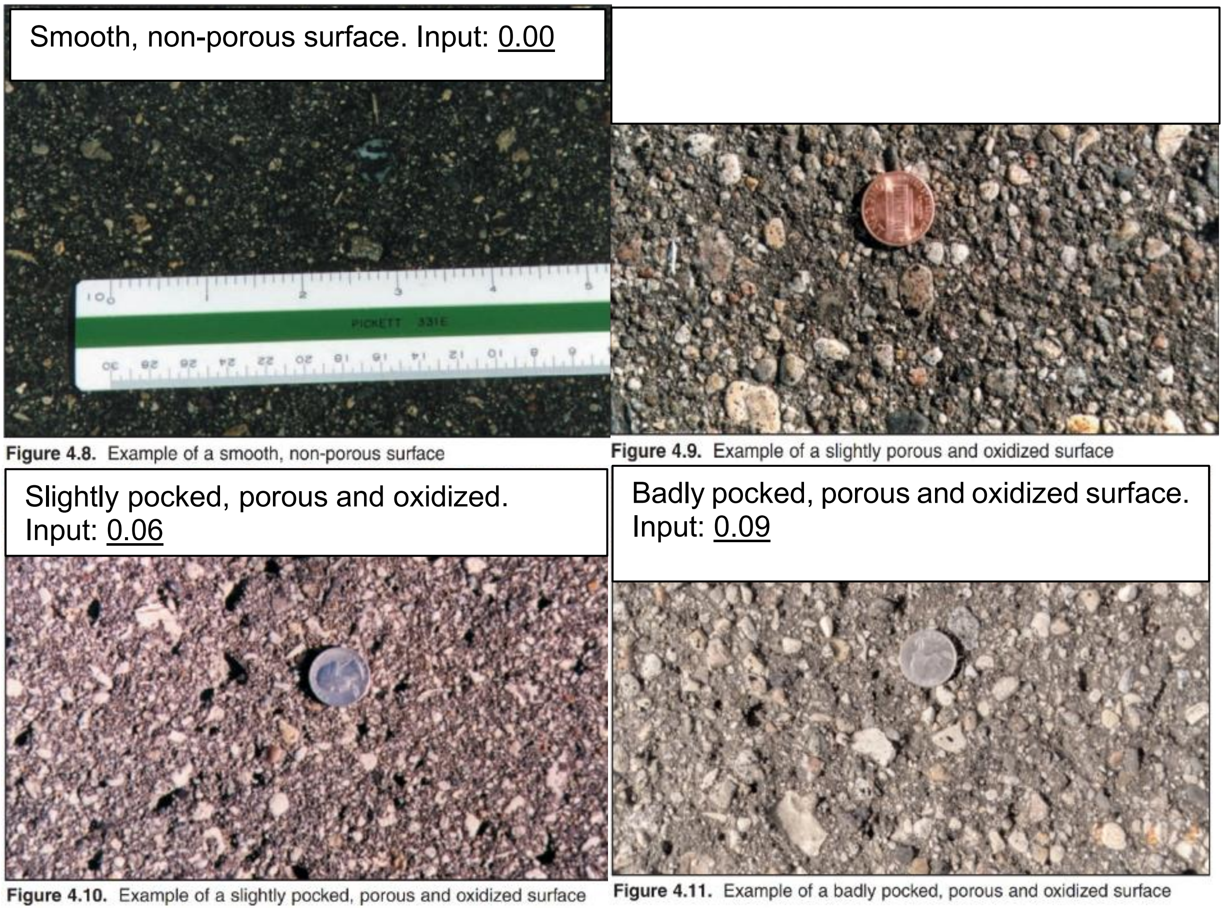


Figure 8-1 Definitions of Pavement Condition for Adjusting Binder Application Rates *after* (Wood et al., 2006).

Table 8-4 Wayne County, Chippewa Rd. North of Smucker Pavement Condition

Distance from intersection (ft)	Lane	Location in Lane	Condition
875	SB	CL	1
875	SB	IWP	1
625	SB	CL	1
625	SB	IWP	1
375	SB	CL	1
375	SB	IWP	1
125	SB	CL	1
125	SB	IWP	1
		Average Southbound Condition	**1**
125	NB	CL	2
125	NB	IWP	1
375	NB	CL	2
375	NB	IWP	1
625	NB	CL	2
625	NB	IWP	1
875	NB	CL	2
875	NB	IWP	1
		Average Northbound Condition	**1.44**

Table 8-5 Wayne County, Chippewa Rd. South of Smucker Pavement Condition

Distance from intersection (ft)	Lane	Location in Lane	Condition
125	SB	CL	2
125	SB	IWP	2
375	SB	CL	2
375	SB	IWP	2
625	SB	CL	2
625	SB	IWP	2
875	SB	CL	2
875	SB	IWP	2
		Average Southbound Condition	**2**
875	NB	CL	2
875	NB	IWP	3
625	NB	CL	3
625	NB	IWP	2
375	NB	CL	3
375	NB	IWP	2
125	NB	CL	3
125	NB	IWP	2
		Average Northbound Condition	**2.5**

The McLeod method is limited in its ability to accommodate varying types of pavement conditions, particularly when the condition varies between two categories. If the pavement condition steadily decreased throughout the section, the field team could increase the binder application rate appropriately. However, this is not the case on Chippewa Road. The location for these test sections is also at an intersection. This creates a challenge as bleeding can decrease the skid resistance and subsequently reduce safety of the intersection. Recognizing that the risk of bleeding is higher for RAP sections, the RAP would be best placed along sections with more consistent pavement condition. These consistent conditions were observed along the Southbound lane. For the Northbound lane, which will use virgin aggregate in the proposed chip seal design, the best option is adjust the surface correction factor by splitting the difference between the two different pavement conditions. Therefore, the surface correction factors are recommended to be as follows, and summarized later in Table 8-8:

- North of Smucker, southbound on Chippewa Rd, S = 0.00,
- South on Smucker, southbound on Chippewa Rd, S = 0.03,
- North of Smucker, northbound on Chippewa Rd, S = 0.015, and
- South on Smucker, northbound on Chippewa Rd, S = 0.045.

8.1.6 Aggregate absorption factor

The aggregate absorption factor is used to account for the binder that is absorbed by the aggregate. The McLeod method suggests absorption factors as described in Table 8-6.

Table 8-6 Aggregate absorption factors

Aggregate Absorption (%)	**Aggregate Absorption Factor, *A*, (gal/yd^2)**
If Absorption < 0.8 %	0.00
If 0.8 ≤ Absorption ≤ 1.8 %	0.02
If Absorption > 1.8%	0.023

Absorption for the virgin aggregate from Wayne county = 1.7%, and absorption for the RAP from Wayne county = 1.6%. Therefore, the aggregate absorption factor (A) = 0.02 gal/yd^2 for both mix designs. This information is summarized later in the report, in Table 8-8.

8.2 McLeod chip seal designs with RAP and virgin aggregate

Based on the aforementioned principles and identified variables, and RAP characterization, the design parameters for the McLeod chip seal design method for RAP and virgin aggregate are summarized in the tables that follow. Table 8-7 shows the aggregate design parameters for McLeod aggregate application rates for the chip seal mix designs for RAP and virgin aggregate from Wayne County, at the target chip seal gradation. Table 8-8 shows the traffic and pavement surface parameters for the McLeod binder application rates for the RAP and virgin chip seal mix designs for Wayne County. A residual asphalt content, R, of 65% was assumed for the chip seal emulsion that will be used by the county in placing these chip seal mixes. It was also assumed the same emulsion used for chip seals placed with virgin aggregate and will also be used for the chip seals placed with RAP.

Table 8-7 Aggregate design parameters for McLeod aggregate application rate

Property	RAP	Virgin
Absorption, *A* (%)	1.6	1.7
Bulk Specific Gravity, *G*	2.441	2.663
Flakiness Index, *F* (%)	11.38	10.75
Loose Unit Weight, W, (AASHTO T 19)	85*	96
Median Size, *M* (inches)	0.27	0.35
Wastage factor, *E*	1.05	1.05
Voids in Loose Aggregate, *V* (%)	44.196	42.23
Average Least Dimension, *ALD* (inches)	0.21	0.26

*The loose unit weight of the RAP is less than the recommended 90 pounds.

Table 8-8 Traffic and pavement surface parameters for McLeod binder application rate

Property	Rap	Virgin
Traffic Factor, *T* (North of Smucker) (vehicles/day)	0.75	0.75
Traffic Factor, *T* (South of Smucker) (vehicles/day)	0.70	0.70
Aggregate Absorption Factor, *A*, (gal/yd^2)	0.02	0.02
Residual Asphalt Content, *R*, (%)	65	65
Surface Condition Factor North of Smucker, Southbound, *S* (gal/yd^2)	0.00	-
Surface Condition Factor North of Smucker, Northbound, *S* (gal/yd^2)	-	0.015
Surface Condition Factor South of Smucker, Southbound, *S* (gal/yd^2)	0.03	-
Surface Condition Factor South of Smucker, Northbound, *S* (gal/yd^2)	-	0.045

8.2.1 Aggregate design equation

Using the values presented in Tables 8-7 and 8-8, the aggregate application rate can be determined through the following equation:

$$C_M = 46.8 \times (1 - 0.4V) \times (ALD \times G \times E)$$

where,

C_M is the aggregate application rate (lb/yd^2) for the McLeod method,
V is the voids in loose aggregate (in percent expressed as a decimal),
ALD is the average least dimension (inches),
G is the bulk specific gravity of the aggregate, and
E is the wastage factor for traffic whip-off.

Application rates determined from this formula are presented in Table 8-9.

8.2.2 Binder design equation

The goal of the binder application rate is to both fill the void space between the aggregates and cover the aggregate without providing excess binder coverage. In an ideal circumstance, the wheel path orients the aggregate to the ALD. However, this does not necessarily occur optimally, especially on low traffic volume roads. Thus, to ensure this coverage is achieved, the average is taken of the binder application rate based on the ALD and the binder application rate based on the median particle size. This provides a slightly conservative binder coverage that ensures optimal performance without adding surplus binder. Using the values presented in Tables 8-7 and 8-8 the binder application can be calculated as follows:

$$B_1 = \frac{2.244 \times (ALD \times T \times V) + S + A}{R}$$

$$B_2 = \frac{2.244 \times (M \times T \times V) + S + A}{R}$$

$$B_M = \frac{B_1 + B_2}{2}$$

where,

ALD is the average least dimension (inches),
T is the traffic correction factor (based on veh/day from Table 2-1),
V is the voids in loose aggregate (in percent expressed as a decimal),
S is the surface condition factor (gal/yd^2), based on existing surface based on Table 2-2,
A is the aggregate absorption factor (gal/yd^2),
R is the percent residual asphalt in the emulsion expressed as a decimal (For asphalt cement, R = 1),
M is the median particle size, and *B* is the binder application rate (gal/yd^2),
B_1 is the binder application rate based on the ALD,
B_2 is the binder application rate based on the median particle size, and
B_M is the averaged binder application rate for the McLeod method.

Application rates determined from these formulas are presented in Table 8-9.

8.2.3 Summary of McLeod mix design starting parameters

Based on the equations presented in sections 8.2.1 and 8.2.2, Table 8-9 presents the aggregate and binder application rates for both the RAP and virgin mixes on Chippewa Road, North and South of Smucker Road for the McLeod mix design method. The varying roadway conditions lead to varying binder application rates on each side of the intersection.

Table 8-9 Summary of Application Rates for Wayne County based on McLeod

Road	Location	Direction	Mix Name	Aggregate Application Rate, C_M, (lb/yd^2)	Binder Application Rate, B_M, (gal/yd^2)
Chippewa	North of Smucker	NB	Virgin Mix 1	28.7	0.38
Chippewa	South of Smucker	NB	Virgin Mix 2	28.7	0.40
Chippewa	North of Smucker	SB	Rap Mix 1	21.0	0.31
Chippewa	South of Smucker	SB	Rap Mix 2	21.0	0.33

8.2.4 Binder application rate adjustment for McLeod

The binder application rates shown in Table 8-8 are only starting application rates. Based on site conditions, the binder application rate may need to be further adjusted according to the condition of the surface along the road, since the nature of the surface affects the amount of binder needed to fill both the voids between the chips and the spaces between pavement macrotexture and pavement irregularities, as well as account for the absorption of binder by the underlying pavement layers. As the traffic loading decreases, the amount of binder increases to account for the lack of compaction so that the target voids in the seal coat may be obtained. A highly oxidized and porous pavement needs more binder to account for increased penetration values and pavement absorption, along with more binder to cover surfaces with an increased texture depth when compared to smooth and non-porous surfaces.

Figures 8-2 through 8-5 are provided based on the aforementioned designs to be referenced during field application, as necessary.

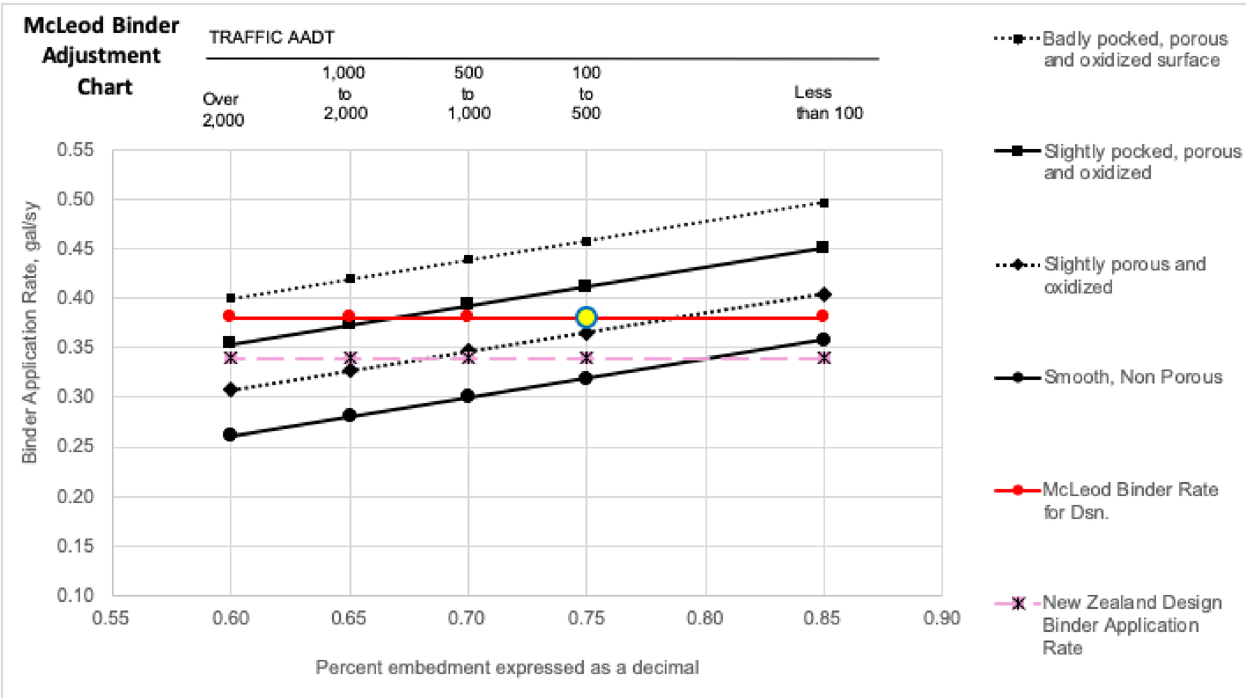


Figure 8-2 Field binder adjustment chart for Virgin Mix 1 (North of Smucker, Northbound) (McLeod

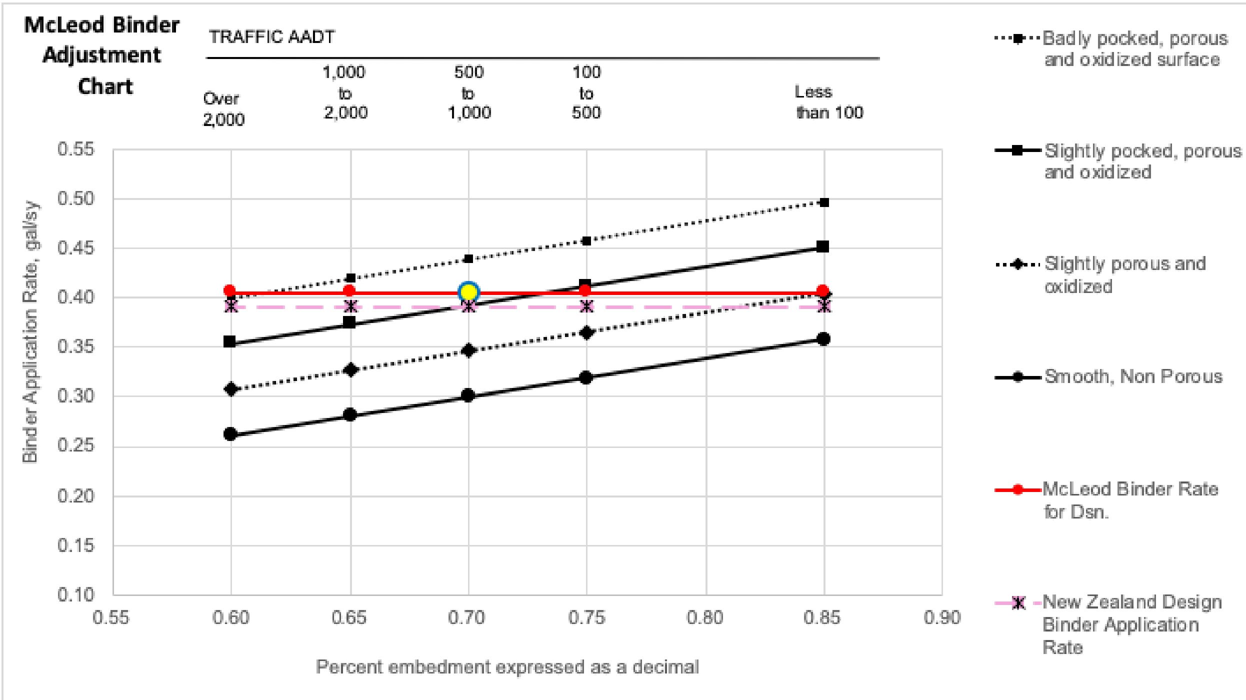


Figure 8-3 Field binder adjustment chart for Virgin Mix 2 (South of Smucker, Northbound) (McLeod design)

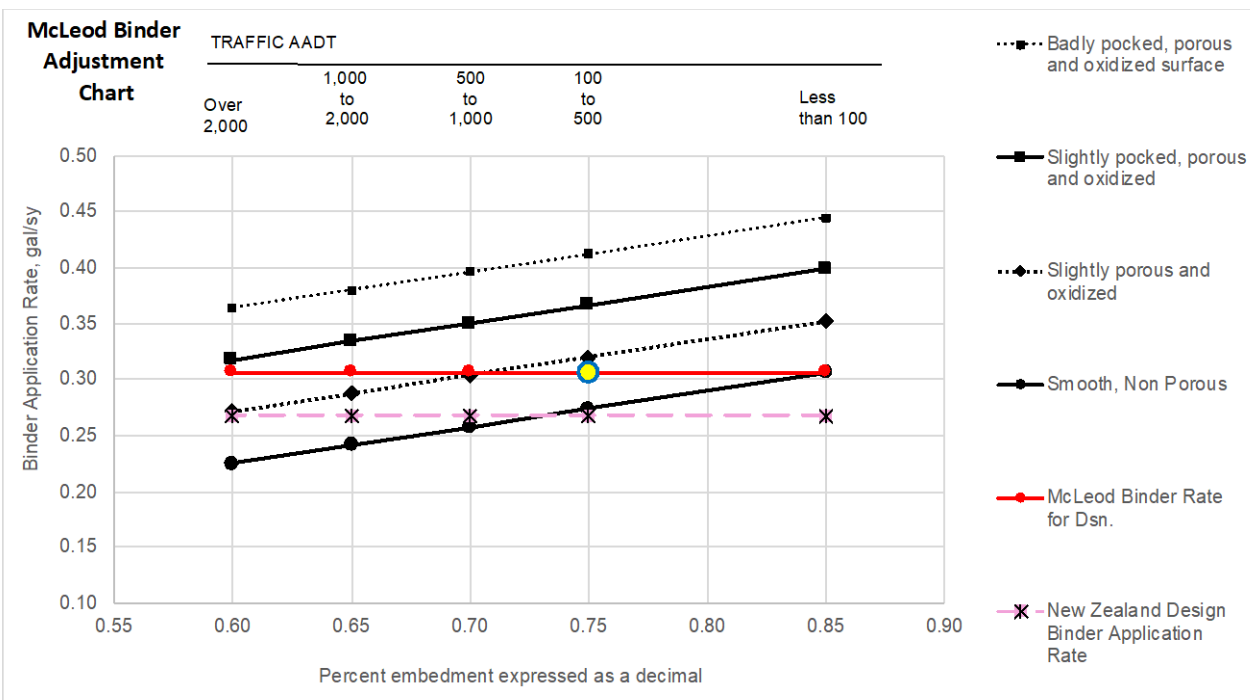


Figure 8-4 Field binder adjustment chart for RAP Mix 1 (North of Smucker, Southbound) (McLeod design)

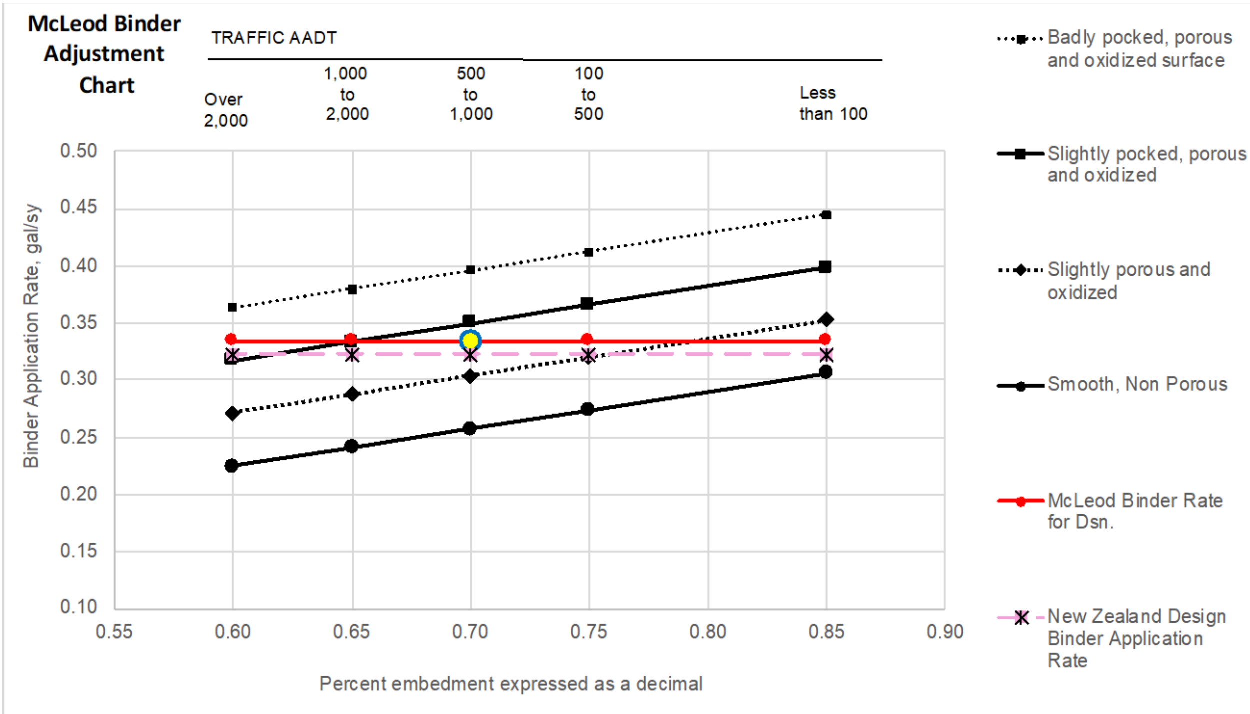


Figure 8-5 Field binder adjustment chart for RAP Mix 2 (South of Smucker, Southbound) (McLeod design)

8.3 New Zealand methodology overview

In the New Zealand design approach, pavement conditions such as the presence of existing pavement seals, roadway macrotexture, surface hardness and structural capacity are taken into consideration.

8.3.1 Traffic factor

The traffic factor helps account for the change in chip orientation caused by varying traffic volumes. Unlike the McLeod method, the New Zealand method focuses exclusively on the percent of trucks. The traffic factor for the project is shown below, based on the assumed percentage of trucks on the route. If the percent of trucks on the route is less than 12%, the traffic factor has a value of 2; however, if the percentage of trucks exceeds 12%, the traffic factor is calculated as a function of the percentage of trucks as:

$$TF = 1 + 0.09 * T$$

where,

TF is the traffic factor, and
T is the percentage of trucks expected on the pavement.

The percentage of trucks on the project is assumed to be less than 12%, therefore TF is equal to 2.

8.3.2 Equivalent light vehicles

The equivalent light vehicles *(ELV)* converts the percent of heavy commercial vehicles to the equivalent number of vehicles or cars to better predict the traffic volume. The underlying assumption is that one truck is equal to 10 cars. The ELV can be calculated as:

$$ELV = \frac{AADT}{T} \text{ X } (1 + 0.9 \text{ X L})$$

where,

ELV is the equivalent light vehicles
AADT is the annual average daily traffic (see section 2.1.3),
T is the percentage of trucks expected on the pavement, and
L is the number of lanes to be sealed (1 across each section).

On Chippewa North of Smucker Road, the *ELV* is equal to 763.36. On Chippewa South of Smucker Road, the *ELV* is equal to 1505.92

8.3.3 Existing pavement texture and hardness

The existing pavement texture plays an important role in determining the binder application rates. Pavements with a large macrotexture (pavement texture depth) would need a higher amount of asphalt binder to first cover the macrotexture before chips can be embedded into the layer of asphalt. In following the New Zealand method for chip seal design, the pavement texture is characterized by the texture depth, measured by the sand circle test. The sand circle test (TNZ T/3:1981) is similar to the test commonly referred to as the sand patch test (ASTM E965) with the exception that sand is used rather than glass beads as are allowed in ASTM E965. For this project, the research team utilized Ohio Department of Transportation's Circular Track (CT) Meter, from which mean profile depth (*MPD*) is determined through the use of laser-displacement sensors. MPD is correlated to mean texture depth (*MTD*), using the equation presented in ASTM E2157:

$$MTD = 0.976MPD + 0.069$$

where,

MTD is mean texture depth (mm), and
MPD is mean profile depth (mm).

CT Meter testing was conducted on Chippewa Road north and south of the intersection with Smucker Road in Wayne County. As noted previously, four test sections are proposed, with each being 1,000 feet in length. Two, one in each lane, are planned at the first 1,000 feet north of the intersection with Smucker Road. The other two sections are planned at the first 1,000 feet south of the intersection, such that there is one section in each lane. The 1000-ft test sections were divided into 4 subsections, in which testing was conducted in the middle of each subsection in the centerline (CL) of each lane and in the inside wheel path (IWP) of each lane.

The average pre-seal pavement texture, T_d, is the average of the MTD over all test results within a single section and is presented in Tables 2-9 and 2-10.

$$T_d = \frac{\sum_{i=1}^{n} MTD_n}{n}$$

where,

T_d is the average pre-seal pavement texture,
MTD is the mean texture depth, and
n is the number of samples taken.

The results of the CT meter testing and calculated MTD are tabulated in Tables 8-10 and 8-11. It should be noted, the existing pavement surface in all four proposed test sections are chip seal pavement.

Table 8-10 CT meter test results north of Smucker, Wayne County

Location:	WAYNE County, Chippewa Rd., North of Smucker			
Date:	5/24/2021			
Ball Size:	19 mm			
Distance from intersection (ft)	Lane	Location in Lane	MPD	MTD
875	SB	CL	1.13	1.14
875	SB	IWP	0.44	0.49
625	SB	CL	0.65	0.68
625	SB	IWP	0.41	0.46
375	SB	CL	1.03	1.04
375	SB	IWP	0.28	0.33
125	SB	CL	0.81	0.84
125	SB	IWP	0.37	0.42
			T_d =	**0.68**
125	NB	CL	0.79	0.82
125	NB	IWP	0.40	0.45
375	NB	CL	1.05	1.06
375	NB	IWP	0.46	0.50
625	NB	CL	0.91	0.93
625	NB	IWP	0.48	0.52
875	NB	CL	1.18	1.17
875	NB	IWP	0.29	0.34
			T_d =	**0.72**

Table 8-11 CT meter test results south of Smucker, Wayne County

Location:	WAYNE County, Chippewa Rd., South of Smucker			
Date:	5/24/2021			
Ball Size:	19 mm			
Distance from intersection (ft)	**Lane**	**Location in Lane**	**MPD**	**MTD**
125	SB	CL	1.14	1.15
125	SB	IWP	0.59	0.63
375	SB	CL	1.7	1.68
375	SB	IWP	0.79	0.82
625	SB	CL	1.5	1.49
625	SB	IWP	0.87	0.89
875	SB	CL	0.63	0.67
875	SB	IWP	0.47	0.51
			T_d =	**0.98**
875	NB	CL	1.54	1.53
875	NB	IWP	0.74	0.77
625	NB	CL	1.68	1.66
625	NB	IWP	0.77	0.80
375	NB	CL	1.84	1.81
375	NB	IWP	0.84	0.86
125	NB	CL	1.58	1.57
125	NB	IWP	0.77	0.80
			T_d =	**1.22**

8.3.4 Average least dimension (ALD) and soft substrate

The initial ALD is calculated the same in both the McLeod and New Zealand Chip Seal Design Methods (see section 8.1.2). However, in the New Zealand method, ALD needs to be adjusted for the binder application rate if the substrate is soft. The adjustments are made based on the ball penetration results in accordance with Table 8-12.

Table 8-12 New Zealand Method ALD adjustment

Ball Penetration Values (in mm)	**ALD adjusted value, ALD_{NZ} (in inches)**
If Average $\leq$ 1	ALD_{NZ} = ALD + 1/25.4
If 1 < Average < 3	ALD_{NZ} = ALD
If 3 $\leq$ Average $\leq$ 4	ALD_{NZ} = ALD – 1/25.4
If Average > 5	Substrate is too soft for a normal chip seal

The ball penetration test (TNZ P/17:2002) measures the hardness of the pavement and dictates if any adjustment in binder application rate is needed. Ball penetration tests were conducted at the same locations as the CT meter testing. In the ball penetration test, a 19 mm ball bearing is placed on the pavement surface and a standard Marshall hammer is dropped on the ball bearing. The depth the ball bearing penetrated the surface is then measured, as shown in Figure 8-6. The results of the ball penetration tests are provided in Table 8-13 and 8-14.

Figure 8-6 Ball Penetration Test on Chippewa Rd., Wayne County, OH

Table 8-13 Ball penetration test results north of Smucker, Wayne County

Location:	WAYNE County, Chippewa Rd., North of Smucker		
Date:	5/24/2021		
Ball Size:	19 mm		
Distance from intersection (ft)	**Lane**	**Location in Lane**	**Ball Penetration Depth (mm)**
875	SB	CL	4.82
875	SB	IWP	4.47
625	SB	CL	3.37
625	SB	IWP	2.45
375	SB	CL	3.33
375	SB	IWP	3.55
125	SB	CL	3.02
125	SB	IWP	3.15
		Average:	**3.52**
125	NB	CL	3.84
125	NB	IWP	2.81
375	NB	CL	4.05
375	NB	IWP	3.33
625	NB	CL	3.65
625	NB	IWP	3.81
875	NB	CL	2.98
875	NB	IWP	3.05
		Average:	**3.44**

Table 8-14 Ball penetration test results south of Smucker, Wayne County

Location:	WAYNE County, Chippewa Rd., South of Smucker		
Date:	5/24/2021		
Ball Size:	19 mm		
Distance from intersection (ft)	**Lane**	**Location in Lane**	**Ball Penetration Depth (mm)**
125	SB	CL	2.08
125	SB	IWP	1.21
375	SB	CL	4.40
375	SB	IWP	2.17
625	SB	CL	2.44
625	SB	IWP	2.19
875	SB	CL	2.70
875	SB	IWP	2.76
		Average:	**2.49**
875	NB	CL	2.73
875	NB	IWP	2.54
625	NB	CL	4.58
625	NB	IWP	2.57
375	NB	CL	2.63
375	NB	IWP	2.71
125	NB	CL	2.20
125	NB	IWP	2.49
		Average:	**2.81**

Based on the ball penetration test North of Smucker (Table 8-13) and the adjustment factors presented in Table 8-12, the values fall between 3mm and 4mm, which means the ALD needs to be reduced by 1/25.4 (which includes a 1mm reduction and the conversion from mm to inches). According to the results of the ball penetration test South of Smucker (presented in Table 8-14, with an average between 1mm and 3 mm), no adjustments are needed for the New Zealand adjusted ALD (ALD_{NZ}). Table 8-15 presents the final values of the New Zealand adjusted ALD for each section.

Table 8-15 New Zealand Adjusted ALD

Road Name	**Location**	**Direction**	**Initial *ALD* (inches) (McLeod)**	**ALD_{NZ} (inches)**
Chippewa	North of Smucker	NB	0.26	0.22
Chippewa	South of Smucker	NB	0.26	0.26
Chippewa	North of Smucker	SB	0.21	0.17
Chippewa	South of Smucker	SB	0.21	0.21

8.3.5 Residual binder volume

The residual binder application rate for the New Zealand design considers the traffic pattern and ALD_{NZ} to determine the amount of binder required to ensure that 35% of the voids have been filled by the first frost. This reduces the amount of chip loss during the first cold snap. An underlying assumption of this calculation is there are 100 days between the completion of the seal and the first frost. The residual binder application rate can be determined by the following equation:

$$V_b = (ALD_{NZ} * 25.4 + 0.7T_d) \times (0.291 - (0.025 \times \log_{10}(TF \times ELV \times 100)) \times 0.220881$$

where,

V_b is the residual binder volume (gal/yd^2),
ALD_{NZ} is the average least dimension of the aggregates (inches),
T_d is the average pre-seal pavement texture derived from sand circle tests,
TF is the New Zealand traffic factor, and
ELV is the equivalent light vehicles including trucks.

The values of V_b are summarized later in the report, in Table 8-16.

8.4 New Zealand chip seal designs with RAP and virgin aggregate

The New Zealand method of chip seal design considers the loose unit weight of aggregate, as well as the ALD, to determine an aggregate application rate. The truck volume, pre-seal surface texture, chip ALD, and pre-seal pavement texture are used to determine the residual binder volume. This value, in addition to corrections for surface conditions, chip shape, and residual asphalt are used to recommend an initial binder application rate. This binder application rate can then be adjusted in the field, as necessary.

8.4.1 Aggregate design equation

The aggregate application rate for the New Zealand method uses the average least dimension of the aggregate and the loose unit weight to determine the aggregate application rate, as follows:

$$C_{NZ} = \left(\frac{1}{\left(\frac{750}{ALD \times 25.4} \right)} \times W \times 16.0185 \right) \times 1.84335$$

where,

C_{NZ} is the aggregate application rate (lbs/yd^2) for the New Zealand method,
ALD is the average least dimension of the aggregates (inches), and
W is the loose unit weight of the aggregates (lbs/ft^3).

The values necessary to calculate C_{NZ} for each mix are summarized later in the report, in Table 8-17. The value of C_{NZ} is then reported in Table 8-18.

8.4.2 Binder design equation

The binder application rate for the New Zealand chip seal design method is a balance between too much binder which would cause flushing, and too little binder which would cause chip loss. The binder application rate equation uses the adjusted ALD (ALD_{NZ}) based on the ball penetration test, the residual binder volume (V_d). The binder design equation can also accommodate for factors such as absorptive surfaces, steep grade, low traffic volumes, chip shape adjustments, and residual asphalt content. This is because, absorptive surfaces (A_s) require a greater amount of binder. Absorptive surfaces are defined as open graded porous asphalt, an open-graded emulsion mix, or a grader-laid asphalt. On steep grades (G_s), slow moving heavy vehicles can cause premature flushing to the surface. Low traffic volumes (U_s) can cause a large amount of chip loss along centerlines and in parking lanes. The traffic volume is considered low if the ELV divided by the number of lanes is less than 100. The chip shape adjustment (C_s) is used because flakey or misshapen chips may not properly interlock or may break under traffic. An adjustment needs to be made then when the ALD to Average Greatest Dimension (AGD) is greater than the ratio 1:2.25. In this research, the AGD for the virgin mix was calculated to be 0.6375, which leads to a ratio of 1:3.333. The RAP mix AGD was calculated to be 0.70, which leads to a ratio of 1:2.45. In both cases, the chip size is within the required threshold.

$$B_{NZ} = (V_b + A_s + G_S + U_s) \times \frac{1 + \frac{C_S}{100}}{\frac{R}{100}}$$

where,

B_{NZ} is the averaged binder application rate for the New Zealand method,
V_b is the residual binder volume (gal/yd^2),
A_s accounts for an absorptive surface (A_s = 0 because it is overlaying an existing chip seal),
G_s accounts for a steep grade (G_s = 0 in Wayne County),
U_s accounts for low traffic volume (Chippewa Road does not have low traffic volumes, U_s = 0),
C_s accounts for an allowance for chip shape (C_s = 0 in Wayne County), and
R is the percent residual asphalt in the emulsion expressed as a decimal.

The values for computing B_{NZ} are presented in Table 2-16.

8.4.3 Summary of New Zealand mix design starting parameters

Table 8-15 summarizes the variables used in to determine the New Zealand aggregate application rates based on the formula presented in section 8.4.1. Table 8-17 then summarizes the variables in the New Zealand binder application rate based on the formula provided in section 8.4.2. Table 8-18 presents the aggregate and binder application rates for both the RAP and Virgin mixes on Chippewa Road, North and South of Smucker Road for the New Zealand mix design method.

Table 8-16 Variables in New Zealand Aggregate Application Rate

Road Name	Location	Direction	Mix Name	ALD_{NZ} (inches)	W (lbs/ft^2)
Chippewa	North of Smucker	NB	Virgin Mix 1	0.26	96
Chippewa	South of Smucker	NB	Virgin Mix 2	0.26	96
Chippewa	North of Smucker	SB	Rap Mix 1	0.21	85
Chippewa	South of Smucker	SB	Rap Mix 2	0.21	85

Table 8-17 Variables in New Zealand Binder Application Rate

Road Name	Location	Direction	Mix Name	V_b (gal/yd^2)	A_s	G_s	U_s	C_s	R
Chippewa	North of Smucker	NB	Virgin Mix 1	0.2214	0	0	0	0	65
Chippewa	South of Smucker	NB	Virgin Mix 2	0.2573	0	0	0	0	65
Chippewa	North of Smucker	SB	Rap Mix 1	0.1737	0	0	0	0	65
Chippewa	South of Smucker	SB	Rap Mix 2	0.2070	0	0	0	0	65

Table 8-18 Summary of Application Rates for Wayne County based on New Zealand Design Method

Road Name	Location	Direction	Mix Name	Aggregate Application Rate, C_{NZ} (lbs/yd^2)	Binder Application Rate, B_{NZ} (lbs/yd^2)
Chippewa	North of Smucker	NB	Virgin Mix 1	25.3	0.34
Chippewa	South of Smucker	NB	Virgin Mix 2	25.3	0.40
Chippewa	North of Smucker	SB	Rap Mix 1	18.1	0.27
Chippewa	South of Smucker	SB	Rap Mix 2	18.1	0.32

8.4.4 Binder application rate adjustment for New Zealand

Just as with the McLeod method, the binder application rates shown in Table 8-18 are only starting application rates. Based on site conditions, the binder application rate may need to be further adjusted according to the condition of the surface along the road, since the nature of the surface affects the amount of binder needed to fill both the voids between the chips and the spaces between pavement macrotexture and pavement irregularities, as well as account for the absorption of binder by the underlying pavement layers. Figures 8-7 through 8-10 are provided based on the aforementioned designs to be referenced during field application, as necessary.

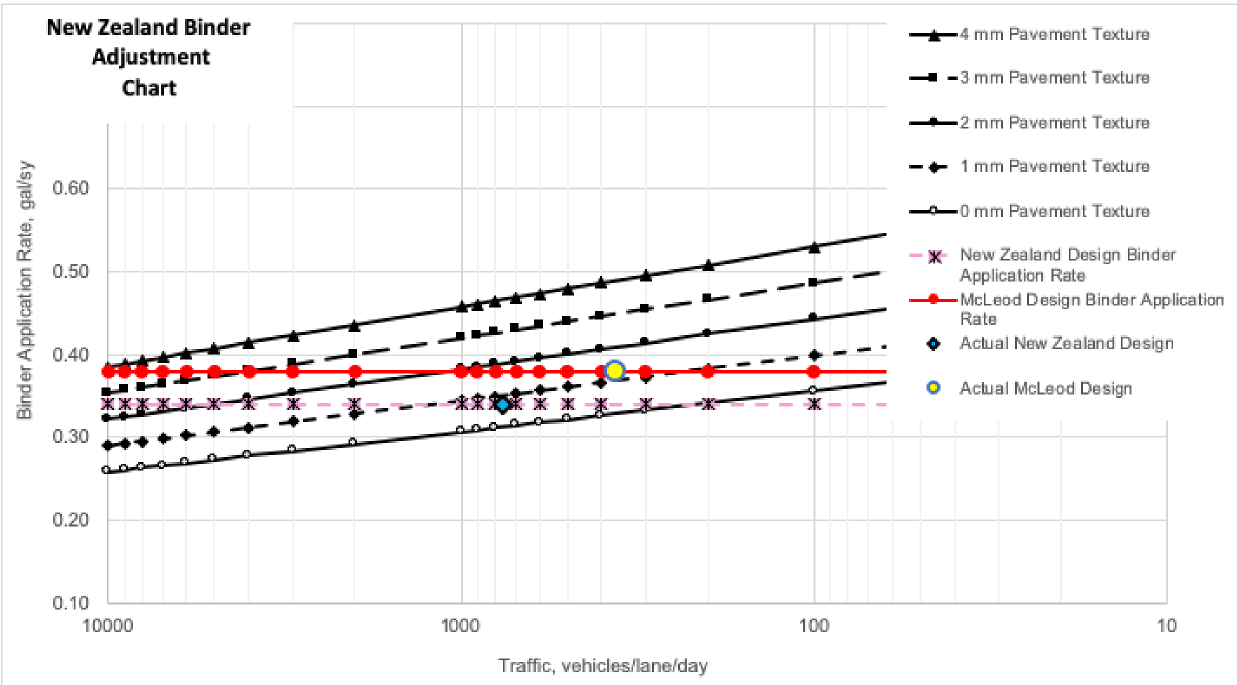


Figure 8-7 Field binder adjustment chart for Virgin Mix 1 (North of Smucker, Northbound) (New Zealand design)

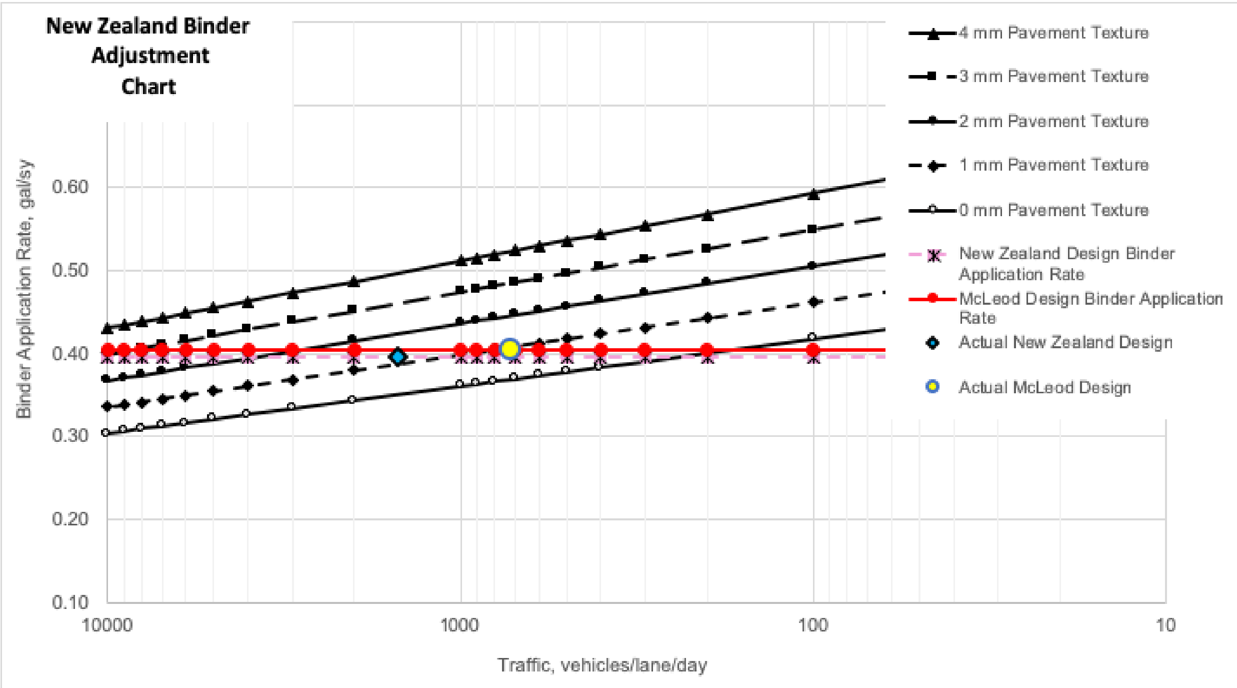


Figure 8-8 Field binder adjustment chart for Virgin Mix 2 (South of Smucker, Northbound) (New Zealand design)

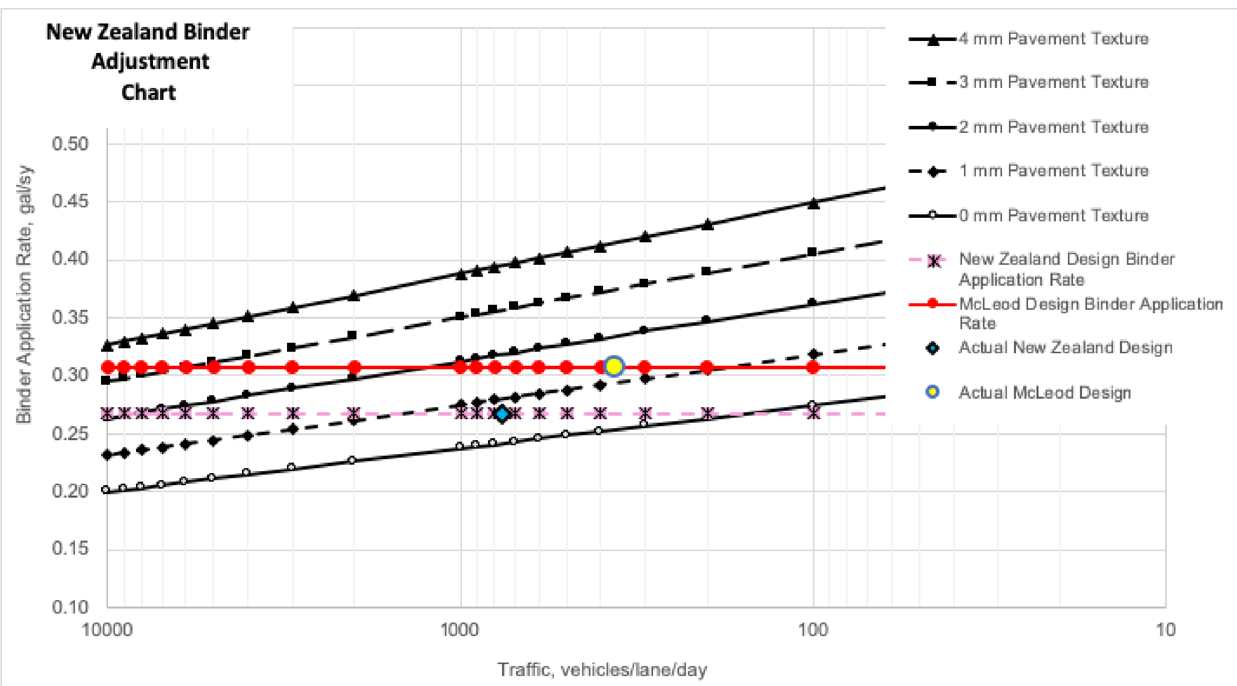


Figure 8-9 Field binder adjustment chart for RAP Mix 1 (North of Smucker, Southbound) (New Zealand design)

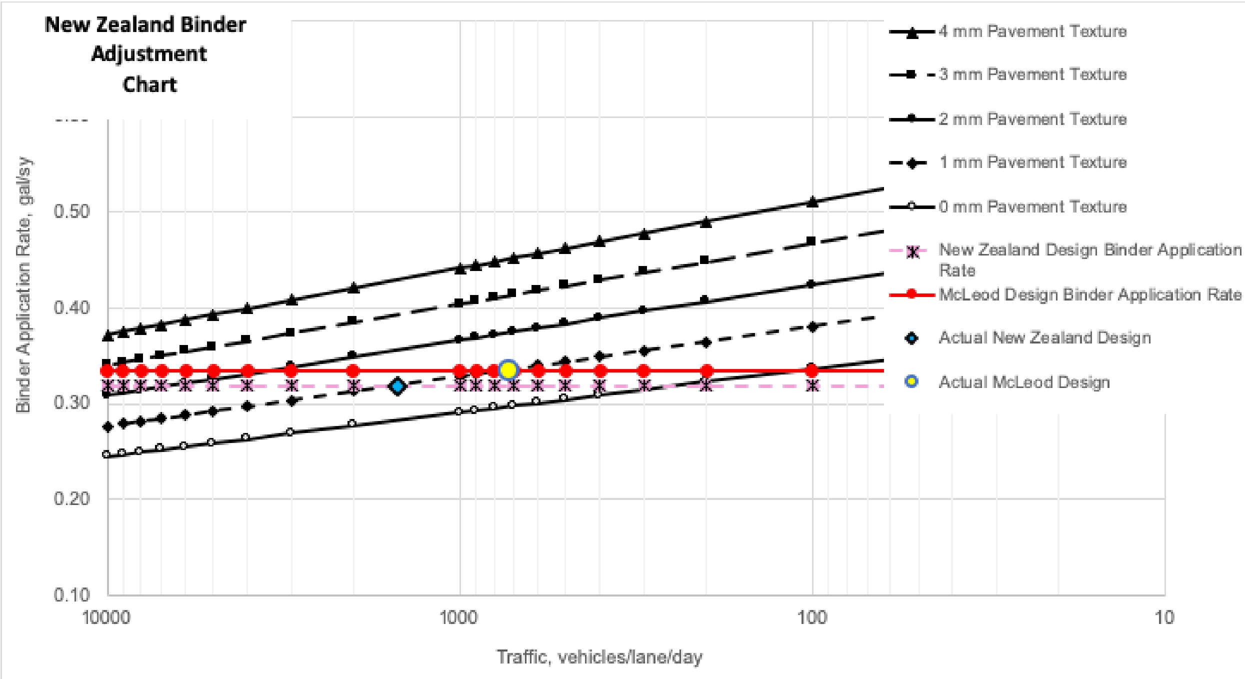


Figure 8-10 Field binder adjustment chart for RAP Mix 2 (South of Smucker, Southbound) (New Zealand design)

8.5 Recommendations and limitations

Table 8-19 provides a summary of the chip seal mix designs per the McLeod method and the New Zealand methods. As can be observed, the binder application rates have a higher differential North of Smucker Drive. The reasons for this discrepancy are presented in the limitations of each method in the section that follows. At the end of the section is the recommendation of the final initial application rates.

Table 8-19 Summary of application starting rates for the aggregate and binder chip seal mixes

				McLeod		New Zealand	
Road Name	**Location**	**Direction**	**Mix Name**	**Aggregate Application Rate, C_M, (gal/yd^2)**	**Binder Application Rate, B_M, (gal/yd^2)**	**Aggregate Application Rate, C_{NZ} (lbs/yd^2)**	**Binder Application Rate, B_{NZ} (lbs/yd^2)**
Chippewa	North of Smucker	NB	Virgin Mix 1	28.7	0.38	25.3	0.34
Chippewa	South of Smucker	NB	Virgin Mix 2	28.7	0.40	25.3	0.40
Chippewa	North of Smucker	SB	Rap Mix 1	21	0.31	18.1	0.27
Chippewa	South of Smucker	SB	Rap Mix 2	21	0.33	18.1	0.32

8.5.1 Primary source of differences between the McLeod and New Zealand Methods

The design approaches for the McLeod and New Zealand method are fundamentally different. The McLeod method focuses on a voids-based approach, where the primary objective is to calculate the void space in the aggregate and fill a certain amount of that space with binder. In contrast, the New Zealand method considers substantially more characteristics of the pavement to make a recommendation on aggregate and binder application rates.

The greatest cause of the difference in binder application rates is due to varying methods for how traffic is calculated. Whereas the McLeod method focuses on filling voids based on the cumulative number of vehicles, the New Zealand method considers the impacts of trucks to the aggregate embedment.

In the McLeod method, the binder application rate is the average of two formulas. The first determines the binder application rate based on the characteristics of the median particle size and the second takes the average based on the characteristics of the ALD. This is done because it is assumed that not all particles will orient to the ALD. If they do not, additional binder is required to provide adequate coverage. The chance of particles not orienting to the ALD is greater when the number of vehicles is lower, such as the case on Chippewa Drive, north of Smucker Driver. As a result, the McLeod method provides a more conservative binder application rate. In contrast, the New Zealand method considers a greater number of vehicles by considering the impact of trucks, where one truck is equal to 10 cars. Therefore, the New Zealand method assumes a higher traffic volume, which leads to a greater movement of aggregate to its ALD, and subsequently requires a lower binder application rate. Of importance, on Chippewa Drive the average number of trucks is assumed to be less than 12 (an assumption that results in the minimum allowable traffic factor in the New Zealand method). This means that, if truck traffic does not reach 12% of all vehicles, then the expected movement of aggregate to its ALD is less likely to occur and a greater amount of binder may be needed than is recommended.

8.5.2 Limitations of the McLeod and New Zealand Methods

There are additional limitations to both the McLeod method and the New Zealand method. In the McLeod method, for example, the whip off factor is dependent on the speed and density of traffic on the roadway. However, a standard formulaic approach does not exist for determining this value and it is left up to the engineer's best judgement when developing the mix design. Existing pavement conditions is also particularly challenging to account for in the McLeod method. The McLeod method is limited in its ability to accommodate varying types of pavement conditions, particularly when the condition varies continuously between two categories. When this occurs, guidelines are limited on how to account for a pavement condition that does not directly align into one of the identified categories. Best engineering judgement must once again be used. It should be noted that, if the pavement condition steadily decreased throughout the section, the field team could increase the binder application rate appropriately as they progress forward.

The New Zealand method uses a different approach that strives to capture more variables than the McLeod method. In the case of steep grade, this value is binary (i.e., does exist or does not exist). In addition, the definition of steep is left up to interpretation. However, varying amounts of steepness could impact the amount of premature flushing. As mentioned earlier, the correction factor assumes that the impact of trucks below 12% (of all traffic) is consistent (i.e., zero trucks has the same impact on particle movement as 12% of traffic being trucks), even if the route does not experience notable trucks (e.g., neighborhoods). This assumption holds true regardless of the total number of vehicles on the road. As vehicle traffic increase, the proportion of traffic also increases, which increases the differential between 12% and 0%.

8.5.3 Expected challenges for Chippewa Road

Due to the fact that the chip seal sections are to be placed on either side of an intersection, and the fact that placement rates vary on each side of the intersection, there are number of factors that may impact the performance of the pavement that should be noted. First, sections leading into the intersection have the potential for high shearing from turning traffic and stopping. Both of these have the potential to negatively impact chip seal performance. Second, chip seal design is not an exact science, which leaves some room for the field crew to adjust as necessary. There is also the potential for too much binder to be applied, which may cause bleeding and reduce skid resistance. As reported in the literature review, some agencies observed bleeding associated with placement of RAP chip seal; therefore, in recognizing this potential for bleeding, the team proposes placing the virgin aggregate on the side with more variable existing surface conditions (i.e., northbound).

8.5.4 Final recommendations

Based on the aforementioned discussion, the research team recommends taking the average of the McLeod and New Zealand method as a starting application rate, as presented in Table 8-20.

Table 8-20 Final recommendation application starting rates for the aggregate and binder chip seal mixes

Road Name	Location	Direction	Mix Name	Aggregate Application Rate, $\overline{C}$, (gal/yd^2)	Binder Application Rate, $\overline{B}$, (gal/yd^2)
Chippewa	North of Smucker	NB	Virgin Mix 1	27.0	0.36
Chippewa	South of Smucker	NB	Virgin Mix 2	27.0	0.40
Chippewa	North of Smucker	SB	Rap Mix 1	19.6	0.29
Chippewa	South of Smucker	SB	Rap Mix 2	19.6	0.33

Because chip seal is more of an art than an exact science, the field team may need to adjust onsite. Adjustments are recommended within the range provided by the McLeod and New Zealand method, with additional assistance from Figures 8-2 through 8-5 (McLeod Method) and Figures 8-7 through 8-10 (New Zealand method). The choice of figures should be chosen based on whether the adjusted application rate moves towards the McLeod method or the New Zealand method's recommended values. The field team should also monitor for bleeding, which will reduce skid resistance at the intersection. If bleeding occurs, binder application rate should be decreased to maximize safety. (*Note:* Conversely, binder application rate may need to be increased if there are patches; however, none were observed in the test sections under consideration.)

9 Design of Microsurfacing Mixes

For this study, a mix design was completed for microsurfacing using RAP milled and retained by the City of Lancaster. This RAP was sampled by the research team and processed in the laboratory through sieving and crushing in a small-scale hammer mill to achieve the desired gradation as discussed in Section 7, Characterization of RAP for use in Microsurfacing and Chip Seals on Local Roadways. A mix design was also completed for comparison with the RAP mix design using virgin aggregate that was sampled from the City of Lancaster and believed to be representative of the aggregate to be used in the placement of test sections in Lancaster. For both virgin aggregate and RAP microsurfacing mix designs, a CSS-1HM emulsion was utilized.

A microsurfacing mix design consists of aggregate, quick setting asphalt emulsion, water and mineral filler mixed in proper proportions so as to ensure a quick break but allows for sufficient mixing time for all the components to mix together and the final mix to be placed. The emulsion content, water content and amount of mineral filler by weight of aggregate all play an important role in determining mixing time and strength gain for a microsurfacing mix. The typical design schematic for a microsurfacing mix is shown in Figure 9-1 below.

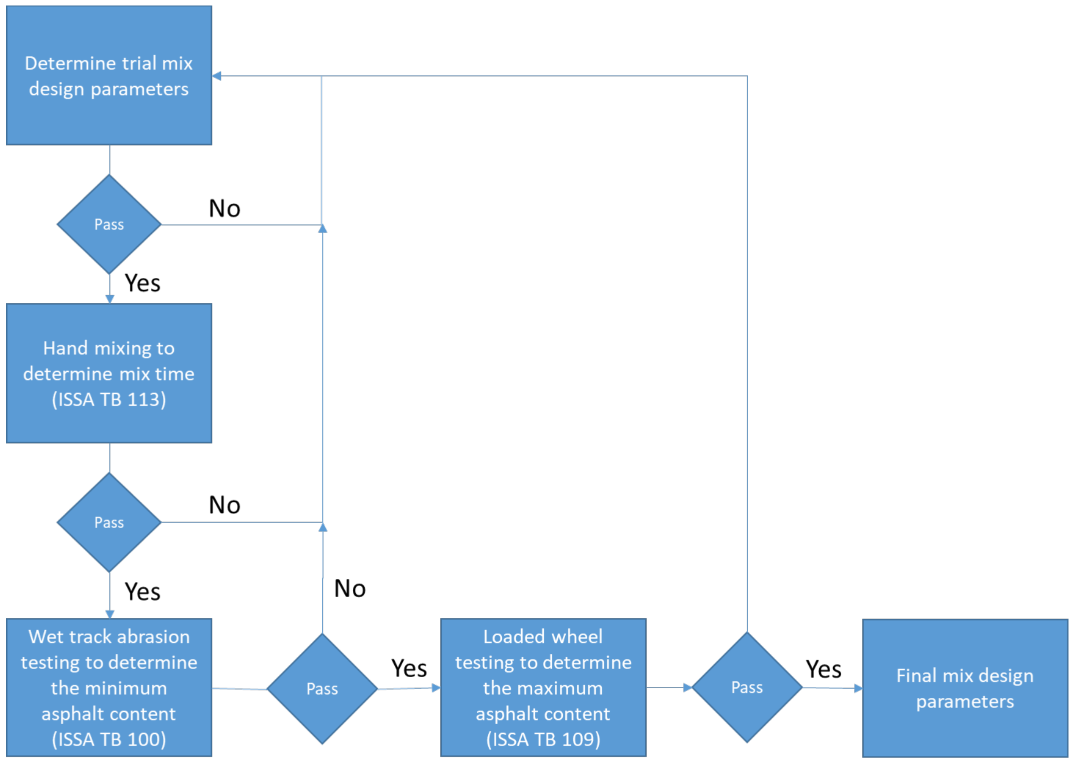


Figure 9-1 Microsurfacing mix design testing process

Apart from the wet track abrasion test (ISSA TB 100) and loaded wheel test for maximum asphalt content (ISSA TB 109), other tests validating the mix design include cohesion testing (ISSA TB 139), wet stripping test (ISSA TB 114) and the Schulze-Breuer and Ruck test (ISSA TB 144). The testing procedure along with results obtained for each test are explained in depth in the following subsections.

Whether a mix passes or fails a test depends on the specification or guidelines utilized for design. Only one agency, LA County, California, has written specifications for microsurfacing mixes using RAP, as documented in the recent FHWA report on the use of RAP in pavement preservation treatments (Duncan et al., 2020) and summarized in Table 9-1. LA County requires 3 tests: ISSA TB-100, TB-106, and TB-113. Many local agencies in Ohio refer to ODOT specifications, therefore, the specifications for ODOT Item 421, microsurfacing mix are also summarized in Table 9-1 for comparison, although they were developed for mixes using virgin aggregate. Listed in the ISSA performance guidelines for microsurfacing, ISSA A143, are requirements for ISSA TB-100, TB-109, TB-113, TB-114, TB-139, TB-144 and TB-147, as shown in the table below. Requirements for ISSA A143 guidelines were developed for microsurfacing mixes using virgin aggregate. The intent is to develop a mix design using RAP from the City of Lancaster with target gradation, as documented in Section 7.3, and develop a mix design for the control section, utilizing virgin aggregate. Therefore, emphasis will be placed on meeting LA County specifications for microsurfacing mixes using RAP.

Table 9-1 Specifications for Microsurfacing Mix: ODOT (virgin aggregate), LA County (RAP), and ISSA A143 (virgin) (*after* ODOT, 2019; Duncan et al., 2020; and ISSA, 2010)

ISSA Test	Description	ODOT Specification (virgin)	LA County (RAP) Specification	ISSA A143 Guideline (virgin)
TB-100	Wet track abrasion loss:			
	1-hour soak	450 g/m^2, max.	646.0 g/m^2	538 g/m^2, max.
	6-day soak	650 g/m^2, max.	810.0 g/m^2	807 g/m^2, max.
TB-106	Slurry seal consistency	N/A	30 mm max.	N/A
TB-109	Excess asphalt by LWT sand adhesion	538 g/m^2, max.	N/A	538 g/m^2, max.
TB-113	Mix time @ 25 °C	Controllable to 120 seconds	N/A	Controllable to 120 seconds, min.
	Mix time @ 40 °C	Controllable to 45 seconds	N/A	N/A
	Mix time at maximum expected air temperature during application	N/A	Controllable to 120 seconds, min.	N/A
TB-114	Wet Stripping	N/A	N/A	Pass (90%, min.)
TB-139	Wet Cohesion:			
	30 minutes min. (set time)	12 kg-cm, min.	N/A	12 kg-cm, min.
	60 minutes min. (traffic)	20 kg-cm, min or near spin	N/A	20 kg-cm, min or near spin
TB-144	Saturated Abrasion Compatibility	2 g loss, max.	N/A	N/A
	Classification compatibility	N/A	N/A	11 Grade Points
TB-147	Lateral displacement	5%, max. (for leveling and rut fill courses only)	N/A	5%, max.
	Specific gravity after 1,000 cycles of 125 lb (56.71 kg)	N/A	N/A	2.10, max.

9.1 Test Method for Determining Mix Time for Slurry Surfacing Systems

The Test Method for Determining Mix Time for Slurry Surfacing Systems (ISSA TB 113), colloquially known as hand mixing, involves mixing together a trial mix design in a bowl to determine the time taken for the emulsion to break and the mixture to set. This test ensures that the microsurfacing mixture has sufficient time to be mixed together and placed, while at the same time achieving sufficient cohesive strength and bond with the aggregates. In turn, this will ensure the microsurfacing can be opened to traffic quickly.

For the hand mixing test, 200g of aggregate were measured and mixed with varying amounts of asphalt emulsion, water and mineral filler (Type 1-2 Portland cement) by weight of aggregate. Hand mixing is typically carried out at room temperature; however, research shows that temperature affects the speed of the emulsion breaking and hence the mixing time. To determine the effect of temperature on the hand mixing time, samples were hand mixed both at 25°C and 40°C. The trial mixes along with hand mixing times are given in Table 9-2.

Table 9-2 Hand Mixing Trail Results

Mix number	Aggregate type	Emulsion content	Water content	Mineral filler	Mix time @25°C (s)	Mix time @40°C (s)
1	RAP	8%	10%	1%	130	40
2	RAP	10%	10%	1%	175	60
3	RAP	12%	10%	1%	195	60
4	RAP	10%	8%	1%	156	50
5	RAP	12%	8%	1%	240	100
6	Virgin	10%	10%	1%	>300	200
7	Virgin	8%	8%	1%	160	40
8	Virgin	10%	8%	1%	268	50
9	Virgin	12%	8%	1%	300	50

Mix times for both RAP and virgin aggregate increase as the water content and emulsion content increase. The RAP mixes had a lower mixing time overall due to a finer mix. Mixing at 40°C showed a decrease in mix time for both RAP and virgin mixes, however the RAP samples had a higher mix time likely due to the coating of asphalt on the aggregates, which reduces the free surface charges available to drive the breaking of the emulsion. The effect of heat on the overall reaction between the aggregate and emulsion is highlighted at 40°C. Despite having a lesser mix time at room temperature, the lack of sufficient free surface charges on the coated aggregate cause a slower break at elevated temperatures.

9.2 Test Method to Determine Set and Cure Development of Slurry Surfacing Systems by Cohesion Tester

ISSA TB 139, Test Method to Determine Set and Cure Development of Slurry Surfacing Systems by Cohesion Tester, lays out the procedure for the cohesion testing of slurry seal and microsurfacing mixes. This test, colloquially known as the cohesion test, calculates the cohesion developed by a slurry seal or microsurfacing mix at two different time intervals (30 minute and 60 minute) in order to determine the *time to set* and *time to traffic* (see Figure 9-2). These are both determined by measuring the torque when a padded foot at 200 KPa pressure is twisted in an arc of 90°-120° on the sample.

- *Time to set* is defined as the time needed for a slurry seal or microsurfacing mixture to set sufficiently so that the expelled water from the coat is clear, which signifies a complete break of the emulsion. The minimum cohesion value necessary for *time to set* is 12Kg-cm.
- *Time to traffic* is defined as the earliest time at which a slurry seal or microsurfacing layer can accommodate traffic on its surface. The minimum cohesion values needed for *time to traffic* is 20Kg-cm.

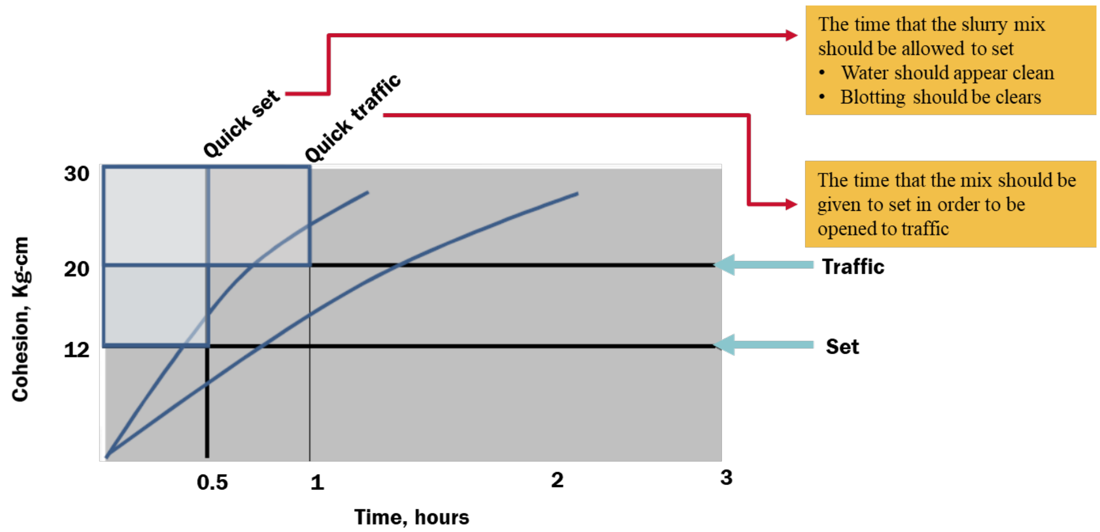


Figure 9-2 Representation of time to set and time to traffic for a slurry seal/microsurfacing mix

To perform the cohesion test, samples are first mixed according to the Test Method for Determining Mix Time for Slurry Surfacing Systems (ISSA TB 113). A starting weight of 200 g of aggregate is chosen and the emulsion and water contents are measured by weight of aggregate. The components are mixed together and cast into circular molds of height 9.5-10.5mm and internal diameter 65-75 mm. The molds are placed on asphalt roofing paper to prevent the absorption of water and asphalt emulsion. Casting is done immediately, approximately 30 seconds after mixing and excess mix is struck off no later than 75 seconds after pouring. The ring mold is then removed after the sample is firm enough to resist flow, but before the samples set completely. The samples are then left to cure at room temperature for either 30 minutes or 60 minutes.

Figure 9-3 shows the cohesion testing device with a padded neoprene rubber foot. The piston is first pressurized to 200 KPa and the sample to be tested is placed below the foot when the required curing time is up. The foot is then allowed to fall on the sample and after 5-6 seconds, the foot is twisted with the help of a torque wrench. The measurement of the torque wrench is recorded as the cohesive force for the mix. The results of cohesion testing for the City of Lancaster is given in Table 3-2.

Figure 9-3 Cohesion tester (Image source: Benedict slurry)

Table 9-3 Results of cohesion testing for microsurfacing mixes (City of Lancaster)

Mix Number	Sample no	Material	Emulsion content	Water content	Time (min)	Cohesion (average) (Kg-cm)
2	1	RAP	10%	10%	30	13
	2	RAP	10%	10%	60	16
4	3	RAP	10%	8%	30	14.33
	4	RAP	10%	8%	60	17.66
5	5	RAP	12%	8%	30	16
	6	RAP	12%	8%	60	19
7	7	Virgin	8%	8%	30	11.5
	8	Virgin	8%	8%	60	15.5
8	9	Virgin	10%	8%	30	12
	10	Virgin	10%	8%	60	16
9	11	Virgin	12%	8%	30	16
	12	Virgin	12%	8%	60	20

Cohesion testing on RAP and virgin samples indicates that a higher asphalt content and a lower water content favor higher cohesion. A relatively lower water content implies that more time is needed for all the water to be expelled from the curing mix, while a higher asphalt content allows for more binding material which leads to a higher cohesion value. RAP samples with both 10% and 12% emulsion at 8% water achieved sufficient cohesion at 30 minutes to pass the 'time to set', however both samples fell short of the 20Kg-cm value for time to traffic at 60 minutes. Despite not achieving the 20Kg-cm value for cohesion, the RAP samples were still considered candidates for further testing since RAP contained existing binder on its surface which could delay the set time of the mix. While higher cohesion values could be achieved with a lower water content and a higher asphalt content, this could result in either a mix with low workability or a higher than optimal asphalt content for the loaded wheel testing. For the virgin aggregate, the sample with 12% emulsion, 8% water and 1% mineral filler passed both the 30-minute 'time to set' and the 60-minute 'time to traffic'.

The acceptable designs based on these results are given in Table 9-4 and include mixes 4, 5 and 9. These mixes were selected to be tested for minimum asphalt content (Wet track abrasion, ISSA TB 100) and maximum asphalt content (Loaded wheel testing, ISSA TB 109), as discussed in the section that follows.

Table 9-4 RAP and Virgin microsurfacing mixes to be tested further

Mix Number	Material	Emulsion content	Water content	Mineral filler
4	RAP	10%	8%	1%
5	RAP	12%	8%	1%
9	Virgin	12%	8%	1%

9.3 Laboratory Test Method for Wet Track Abrasion of Slurry Surfacing Systems

The laboratory test method for Wet Track Abrasion of Slurry Surfacing Systems (ISSA TB 100), colloquially known as the wet track abrasion test, measures the minimum asphalt content needed for a slurry seal or microsurfacing mix design. Two tests are run following this method, one for 1-hour and one for 6-days.

The test consists of an apparatus built from a Hobart mixer which has a rotating head on which a piece of hose is attached. This rotating head is allowed to spin on the slurry seal or microsurfacing sample and dislodge loose asphalt and aggregate. The amount of aggregate lost is measured and is reported as the amount of aggregate lost in grams per square foot or square meter.

The apparatus consists of a Hobart mixer (Model C-100), a quick clamp mounting plate and a flat bottom pan to hold the wet track sample. The sample mold should have a height of 6.35±0.6mm and an internal diameter of 280±6mm. The wet track apparatus is shown in Figure 9-4 below.

Figure 9-4 Wet track abrasion testing equipment

In this test, 800 g of aggregate is measured and mineral filler, water and emulsion are added in accordance with Test Method for Determining Mix Time for Slurry Surfacing Systems (ISSA TB 113). The mix is then cast immediately into the molds for the wet track test placed over asphalt roofing paper after 30 seconds of mixing. The sample is then struck flush with the help of a squeegee within 15 seconds. The mold is then removed when the sample is firm enough to resist flow, but before the sample can set. The wet track discs are then cured in a forced draft oven at 60°C for at least 15 hours but no more than 30 hours. The samples are then removed from the oven, allowed to cool and then weighed for their initial weight. The samples are then placed in a water bath up to a minimum depth of 12.5 mm or 0.5 inches for either 1 hour or 6 days. After the desired soak time, the discs are placed in the wet track pan and covered with water to a depth of 6.35 mm above the sample surface. The sample is clamped in place and the head with the hose is brought in contact with the sample by raising the wet track bowl. The machine is set on its lowest speed and the head is allowed to rotate and abrade the sample for 300 seconds. The sample is then removed from the pan and washed thoroughly to remove any loose aggregate on its surface and then placed in an oven at 60°C to dry till constant weight. The sample is then weighed for a final weight. The weight loss per square foot is calculated by multiplying the weight loss per sample by a factor of 3. For the minimum asphalt content, the weight loss should be no more than 50 g/ft^2 for a 1 hour soak time and 75 g/ft^2 for a 6 day soak time.

The results of the wet track abrasion test for RAP and virgin aggregate microsurfacing samples are given in Table 9-5.

Table 9-5 Wet track abrasion test results for RAP and virgin aggregate

Mix number	Material	Emulsion content	Water content	Soak time	Average weight loss/ft^2	Minimum allowable weight loss		
						ISSA A143	LA County (RAP)	ODOT (virgin)
4	RAP	10%	8%	1 hour	938.80	538g/m^2	646g/m^2	450g/m^2
5	RAP	12%	8%	1 hour	109.39			
9	Virgin	12%	8%	1 hour	123.53			
4	RAP	10%	8%	6 day	750.12	807g/m^2	810g/m^2	650g/m^2
5	RAP	12%	8%	6 day	252.50			
9	Virgin	12%	8%	6 day	712.61			

The RAP sample with 10% emulsion and 8% water did not meet specifications on the maximum allowable weight loss and indicated that a higher asphalt content was required. The RAP sample with 12% asphalt emulsion and 8% water met the ISSA TB 143 specifications for maximum allowable weight loss, along with the virgin aggregate sample with 12% emulsion and 8% water, indicating that the asphalt content of 12% is above the minimum for both samples.

9.4 Test Method for Wet Stripping of Cured Slurry Surfacing Mixtures

The Test Method for Wet Stripping of Cured Slurry Surfacing Mixtures (ISSA TB 114) determines the ability of the mix to remain coated with asphalt under the test conditions. If the asphalt does not properly coat the aggregates, this could result in premature raveling under traffic conditions. The test involves placing a sample of cured mix in boiling water for a set amount of time and determining the percentage of aggregates still coated with asphalt.

For this test, a mix design is prepared in accordance with Test Method for Determining Mix Time for Slurry Surfacing Systems (ISSA 113). Next, 10 g of this mix is collected and allowed to cure for 24 hours at laboratory temperature. A 600 ml beaker is fitted with a fine wire mesh which sits just above the bottom of the beaker, and the beaker is filled with deionized distilled water. The water is brought to a boil, and the 10-g sample of mix is placed on the wire mesh in the beaker.

The mix is allowed to sit in the boiling water for 3 minutes, at which point it is taken off the heat source and allowed to cool for 1-2 minutes. Cold water is then added to the beaker until free asphalt on the surface flows over the side. Care should be taken not to wash out fine aggregate particles of the mix. The mix is then removed from the beaker and wire mesh and placed on a paper towel and allowed to air dry for 24 hours. The mix is then examined, and the approximate percentage of aggregates still coated with asphalt is measured. ISSA TB 114 states that satisfactory mixes should have greater than 90% of the aggregates still completely coated with asphalt. 75-90% of aggregates coated indicates a marginal result, while less than 75% of the aggregates coated with asphalt after the test indicates an unsatisfactory result for this test. The results of the wet stripping test for the mix designs are given in Table 9-6.

Table 9-6 Results of wet stripping test (ISSA TB 114)

Aggregate type	Emulsion content	Water content	Percentage of aggregate still coated with asphalt
Virgin	12%	8%	>90
RAP	12%	8%	>90
RAP	10%	8%	>90

Results of wet stripping tests show that RAP and Virgin microsurfacing samples with 12% emulsion, 8% water and 1% mineral filler as well as the RAP sample with 10% emulsion, 8% water and 1% mineral filler had greater than 90% of the aggregates still coated with asphalt after boiling. All three samples passed the wet stripping test.

9.5 Test Method for Measurement of Excess Asphalt in Bituminous by Use of a Loaded Wheel Tester and Sand Adhesion (ISSA TB 109)

Testing to determine the susceptibility to flushing was conducted for the virgin and RAP microsurfacing mixes following the Test Method for Measurement of Excess Asphalt in Bituminous by Use of a Loaded Wheel Tester and Sand Adhesion (ISSA TB 109). This test is conducted by preparing samples with mix design components as presented in Table 3-3. The amount of aggregate selected is dependent on the maximum aggregate size of the gradation, such that there is 25 to 35% more material than needed to fill the mold. The size of the mold was selected such that it was approximately 25% thicker than the maximum aggregate size in the gradation. For the virgin aggregate, the material was sieved over a 3/8" sieve to remove any stockpile contaminants. RAP aggregate was batched according to the amount needed and the target gradations previously presented in Section 5. Based on the gradation of each material, 375 grams of RAP were used with a ¼" size mold and 500 grams of virgin aggregate were used with a ½" size mold. Mix components, asphalt emulsion, water and Portland cement were calculated by weight of aggregate. Once mix components were weighed, they were mixed rapidly and cast in the mold. Excess material was struck-off and the material was allowed to set long enough to prevent displacement when the mold was removed. The specimens were then dried to a constant weight in a 60°C oven for a minimum of 12 hours.

Once dried to a constant weight and allowed to cool the specimens were then tested in the loaded wheel tester (LWT). The LWT was loaded to 125lbs and 1,000 cycles were applied to each specimen at room temperature. The weight was recorded prior to and after completion of 1,000 cycles in the LWT. Then, 200 g of sand meeting the requirements listed in ISSA TB 109 and heated to 82°C were uniformly spread along the sand frame placed atop the specimen. A metal strip was placed on top of the sand and sand frame and the LWT loaded to 125lbs then applied 100 cycles to each specimen. At the conclusion of testing, loose sand was removed, and a final weight was determined from which the amount of adhered sand was calculated. The weight of adhered sand per unit area was determined by dividing the weight of adhered sand by the area of the metal strip. The results are presented in Table 9-7 and pictures of the resulting specimens are shown in Figure 9-5.

Table 9-7 Results of Excess Asphalt by Sand Adhesion Test

Aggregate Type	Emulsion Content	Water Content	Adhered Sand (g)	Adhered Sand per area (g/m^2)
Virgin	12%	8%	7.1	522
RAP	10%	8%	8.2	603
RAP	12%	8%	7.4	544

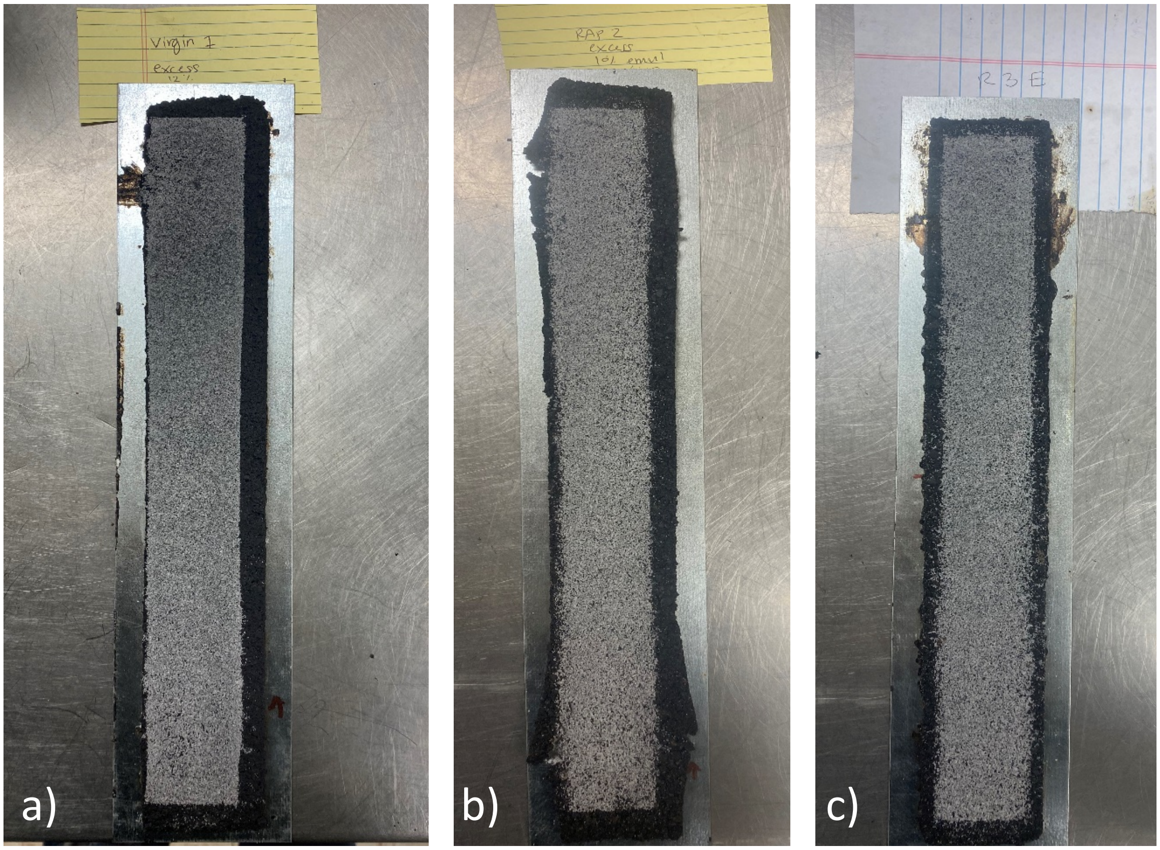


Figure 9-5 Results of Excess Asphalt by LWT and Sand Adhesion: a) Virgin Aggregate at 10% emulsion, b) RAP at 10% emulsion and c) RAP at 12% emulsion

In comparing the results of this test to the requirements listed in Table 9-1 only requirements for microsurfacing using virgin aggregates were identified, as LA County does not list any specifications requirements for this test for microsurfacing produced with RAP. Both ODOT, Item 421 and ISSA A143 guideline specify a maximum area of adhered sand of 538 g/m^2. The microsurfacing mix with virgin aggregate met this requirement with a value of 522 g/m^2, slightly less than the threshold. In comparing the results for the RAP mixes to ODOT and ISSA A143 thresholds for microsurfacing with virgin aggregate, neither the RAP microsurfacing mix with 10% emulsion nor the RAP microsurfacing mix with 12% emulsion met the threshold. However, it should be noted the surface of the RAP mixes was much coarser which would allow more void space for sand to remain trapped. Among the RAP mixes, it was expected the highest emulsion content would result in greater sand adhered to the specimen; however, that was not the case. It is believed the breakdown of the thin RAP sample with 10% emulsion, as shown in Figure 9-5 may have resulted in increased sand to become embedded in cracks which developed toward the end of the thin specimen, which in turn may explain higher sand despite the lower emulsion content.

9.6 Test Method for Classification of Slurry Surfacing Materials Compatibility by Schulze-Breuer and Ruck Procedures (ISSA TB 144)

To evaluate the compatibility between aggregate fines and emulsified asphalt residue for the virgin and RAP microsurfacing mixes, testing was conducted following the Test Method for Classification of Slurry Surfacing Materials Compatibility by Schulze-Breuer and Ruck Procedures (ISSA TB 144). In this test only aggregate fines, material passing the No. 10 sieve, are combined with prescribed amounts of emulsion and filler. The mix is then used to make 40 g sample compacted pills. Pills are then subjected to a 6-day soak in 25°C water and subjected to a series of tests to determine the abrasion loss, integrity (as percent retained) and adhesion (as percent coated). For each test results are compared to thresholds in ISSA TB 144 and assigned a point rating for each. The total points for a mix can then be compared to the minimum points in ISSA A143 guidelines for microsurfacing.

In this test, an aggregate sample size of 200 g is prepared with prescribed proportions of aggregate fractions, as listed in Table 9-8. The aggregate is combined with specified amounts of filler and emulsion. Sufficient amount of water is added to the aggregate and filler to create a slurry prior to the addition of the emulsion. For the samples tested in this study 25 g of asphalt emulsion and 2 g of filler (Portland cement) were utilized. The materials were mixed until the mix was broken. The mixes were then crumbled to a uniform consistently and allowed to air cure for at least one hour prior to being dried to a constant weight at 60°C.

Table 9-8 Aggregate Fractions used in Test for Classification of Slurry Surfacing Materials Compatibility (*after* ISSA TB 144)

US Sieve Size, Passing	US Sieve Size, Retained	% Aggregate
No. 10	No. 30	35%
No. 30	No. 50	25%
No. 50	No. 200	22%
No. 200	Pan	18%

Once dried, 40 g of sample were placed in a preheated mold and pressed into a pill. The pills were then placed in a water bath at 25°C for 6 days. The saturated weight of the pill was taken as the weight after the 6-day soak and blotted to surface dry. The pills were then placed in 750 mL of 25°C water in the cylinders of the abrasion machine and then subjected to 3600 cycles at 20 revolutions per minute (RPM). After completion of testing in the abrasion machine, the pills were blotted to surface dry and weighed. The abrasion loss was then calculated by subtracting the resulting weight from the weight of the saturated pill. A point rating was assigned based on the amount of abrasion loss, as described in ISSA TB 144. The saturated weight and abrasion loss results are presented in Table 9-9. ODOT Item 421 specifies a maximum 2 g loss by abrasion, although this is specific to microsurfacing with virgin aggregate. Both the virgin and RAP microsurfacing specimens meet this requirement.

Table 9-9 Abrasion Loss Results for Compatibility of Slurry Surfacing Materials

Aggregate Type	Saturated Weight (g)	Weight of Abraded Pill (g)	Abrasion loss (g)	Point Rating
Virgin	41.54	40.52	1.02	3
RAP	40.54	40.08	0.46	4

The abraded pills were then placed in 800 mL of boiling water for 30 minutes. Once time had elapsed the pills were surface dried and weighed. In this study, pills remained intact, had they broken apart during boiling, the largest piece remaining would have been weighed. The results are presented in Table 9-10.

Table 9-10 Integrity Retained Results for Compatibility of Slurry Surfacing Materials

Aggregate Type	Saturated Weight (g)	Weight, Integrity (g)	Integrity, Retained	Point Rating
Virgin	41.54	38.13	91.8%	4
RAP	40.54	40.10	98.9%	4

The pills were then allowed to air dry for a minimum of 24 hours. The percent of aggregate completely coated with asphalt was then estimated and recorded as adhesion, percent coated. The results are summarized in

Table 9-11. A picture of pills at the end of testing is shown in Figure 9-6. As seen in the picture, the virgin aggregate sample has some loss of material and less coating on the aggregate.

Table 9-11 Percent Adhesion Coated Results for Compatibility of Slurry Surfacing Materials

Aggregate Type	Adhesion, coated	Point Rating
Virgin	80-85%	3
RAP	95%	4

Figure 9-6 Pills at the Conclusion of ISSA TB 144 Testing; Virgin Aggregate on the Left and RAP on the Right

In comparing the results to ISSA A143 guidelines for microsurfacing, only the RAP mix has total points (12) greater than the minimum of 11 points. Although these guidelines were developed for mixes using virgin aggregate. The only written specification that was identified for RAP microsurfacing mix is for LA County and it does not have any requirements for this test. The virgin mix had a total of 10 points based on the results and therefore falls short of meeting the ODOT requirement. It should be noted, however, the virgin aggregate was sampled from the yard at the City of Lancaster, and while may be representative of the sourced aggregate, some variations may exist which may account for falling short of the requirement.

In comparing the results for virgin and RAP samples, the RAP samples outperformed the virgin samples for all 3 parameters: abrasion loss; integrity, % retained; and adhesion, % coated. This indicates a possible benefit in terms of durability of using RAP as a replacement for virgin aggregate in microsurfacing mixes.

9.7 Test Method for Measurement and Stability and Resistance to Compaction, Vertical and Lateral Displacement of Multilayered Fine Aggregate Cold Mixes (ISSA TB 147)

Testing following the Test Method for Measurement and Stability and Resistance to Compaction, Vertical and Lateral Displacement of Multilayered Fine Aggregate Cold Mixes (ISSA TB 147) was conducted to evaluate the amount of displacement under loading for each microsurfacing mix. Samples were prepared in a similar manner as for the excess asphalt by sand adhesion test (ISSA TB 109). For the virgin aggregate, the material was sieved over a 3/8” sieve to remove any stockpile contaminants, and 500 g were sampled. RAP aggregate was batched according to the target gradations previously presented in Section 5 to achieve a 500-g sample. The remaining mix components, asphalt emulsion, water, and filler were added as percent of weight of aggregate. Components were mixed rapidly, and the mixes were cast in a ½" mold. After a sufficient time passed for the mix to set without free flowing the mold was removed and placed in an oven at 60°C to dry to constant weight for a minimum of 18 hours. Once dry, the specimens were allowed to return to room temperature prior to testing in the LWT.

The width and thickness of the specimens while mounted on the testing plate were determined at the mid-point and 2 inches on either side of the midpoint. The specimens were then subjected to 1000 cycles of the LWT loaded to 125lbs at room temperature. After testing was completed the final width and thickness of the sample were measured at the same three locations. From these measurements the average initial thickness and width and the average final thickness and width were determined. The resulting rut depth was then calculated as a percent of the initial average specimen thickness. The lateral displacement was determined as the percent increase in specimen width relative to the initial average width. Results are tabulated in Table 9-12.

Table 9-12 Results of Vertical and Lateral Displacement Test

Aggregate Type	Emulsion Content	Water Content	Initial		Final		Rut Depth	Lateral displacement
			Avg Thickness (in)	Avg. Width (in)	Avg Thickness (in)	Avg. Width (in)		
Virgin	12%	8%	0.227	1.987	0.183	2.014	19.4%	1.36%
RAP	10%	8%	0.266	1.953	0.217	2.005	18.4%	2.66%
RAP	12%	8%	0.245	1.953	0.217	1.975	11.4%	1.13%

In comparing the results of this test to the requirements listed in Table 9-1, only requirements for microsurfacing using virgin aggregates were identified. Both ODOT, Item 421 and ISSA A143 guideline specify a maximum lateral displacement of 5%. The microsurfacing mix with virgin aggregate at 12% emulsion met this requirement, as did both RAP microsurfacing mixes. ISSA A143 also specifies a maximum specific gravity, however, specific gravity was not determined for these mixes since the ODOT and LA County specifications do not specify limits for specific gravity. Although no thresholds are specified for vertical displacement of microsurfacing mixes with virgin aggregate or microsurfacing mixes with RAP ISSA TB 147 indicates values which "substantially exceed 10% are not satisfactory for uncompacted multilayer applications." While all three mixes exceed 10%, with the microsurfacing mix with virgin aggregate and the microsurfacing mix with RAP and 12% emulsion exceeding the threshold by at least 7.5%, these mixes are intended to be placed in one layer.

9.8 Test Method for Measurement of Slurry Seal Consistency (ISSA TB 106)

Testing to determine the consistency and flowability of the microsurfacing mix designs was done according to ISSA TB 106. Typically, consistency values are used to determine ease of flow into the spreader and general workability when the mix is laid down, particularly for slurry seal treatments. The Recommended Performance Guidelines for Emulsified Asphalt Slurry Seals, A105 (ISSA, 2010) stipulates a minimum slump value of 2 – 3 cm. This test is conducted by preparing the mixes according to ISSA TB 113 (hand mixing of slurry seal and microsurfacing mix designs). The test setup involves a sand absorption cone similar to the apparatus used in ASTM C 128 and a glass flow surface to measure the slump. A tape measure was used to measure the total slump. The base aggregate amount used was 400g and asphalt emulsion, water and mineral filler were added as a percentage of the weight of aggregate. The mixes were hand mixed for 30 seconds and then poured into the cone with the help of a plastic funnel. The cone was then lifted up in a smooth motion and the mix was allowed to flow. The diameter of the flow was measured when the mix flow ceased. The results of the slump test are given in Table 9-13.

Table 9-13: Results of slump test for microsurfacing mixes

Aggregate type	Emulsion content	Water content	Average slump (cm)
Virgin	12%	8%	2.95
RAP	12%	8%	3.2
RAP	10%	8%	2.75

The results indicate the slump for the virgin mix design and RAP at 10% emulsion are within the range recommended by ISSA (2010) in A105. The RAP at 12% emulsion was slightly greater than the maximum recommended by ISSA for slurry seals. It is important to note these values are for slurry seal, as ISSA does not provide recommended values for microsurfacing mixes. LA County does specify a maximum value of 3.0 cm for RAP microsurfacing. Despite, being greater than the maximum required by LA County specification, it is believed performance of the RAP at 12% emulsion will not be affected, as the set time for this mix is within the range allowed by ODOT specification and ISSA A143.

9.9 Recommendation of Mixture

9.9.1 Comparison of Results to ODOT, LA County, and ISSA Specifications

Table 9-14 compares various specifications for microsurfacing mix designs for ODOT Item 421 (virgin microsurfacing mixes), LA county (RAP microsurfacing mixes) and ISSA A143 (virgin microsurfacing mix). RAP (A) refers to the sample with RAP containing 10% emulsion, 8% water and 1% cement while RAP (B) refers to the sample with RAP containing 12% emulsion, 8% water and 1% mineral filler.

Table 9-14 Comparison of Results to Specifications for Microsurfacing Mix: ODOT (virgin aggregate), LA County (RAP), and ISSA A143 (virgin) (*after* ODOT, 2019; Duncan et al., 2020; and ISSA 2010)

ISSA Test	Description	ODOT Specification (virgin)	LA County (RAP) Specification	ISSA A143 Guideline (virgin)	Results from lab testing		
					Virgin	RAP (A)	RAP (B)
TB-100	Wet track abrasion loss:						
	1-hour soak	450 g/m^2, max.	646.0 g/m^2, max	538 g/m^2, max.	123.53	938.80	109.39
	6-day soak	650 g/m^2, max.	810.0 g/m^2, max	807 g/m^2, max.	712.61	750.12	252.50
TB-106	Slurry seal consistency	N/A	30 mm max.	N/A	29.5	27.5	32.0
TB-109	Excess asphalt by LWT sand adhesion	538 g/m^2, max.	N/A	538 g/m^2, max.	522	603	544
TB-113	Mix time @ 25 °C	Controllable to 120 seconds	N/A	Controllable to 120 seconds, min.	300	156	240
	Mix time @ 40 °C	Controllable to 45 seconds	N/A	N/A	50	50	100
	Mix time at maximum expected air temperature during application	N/A	Controllable to 120 seconds, min.	N/A	N/A	N/A	N/A
TB-114	Wet Stripping	N/A	N/A	Pass (90%, min.)	PASS	PASS	PASS
TB-139	Wet Cohesion:						
	30 minutes min. (set time)	12 kg-cm, min.	N/A	12 kg-cm, min.	16	14	16
	60 minutes min. (traffic)	20 kg-cm, min or near spin	N/A	20 kg-cm, min or near spin	20	18	19
TB-144	Saturated Abrasion Compatibility	2 g loss, max.	N/A	N/A	1.02	N/A	0.46
	Classification compatibility	N/A	N/A	11 Grade Points	3	N/A	4
TB-147	Lateral displacement	5% max. (for leveling and rut fill courses only)	N/A	5% max.	1.36%	2.66%	1.13%
	Specific gravity after 1,000 cycles of 125lb (56.71 kg)	N/A	N/A	2.10 max.	N/A	N/A	N/A

Based on the comparison of the results presented in Table 9-13, the recommended mix designs are presented in Table 9-15.

Table 9-15: Final mix design recommendation

Aggregate type	Emulsion content	Water content	Cement content
Virgin	12%	8%	1%
RAP	12%	8%	1%

Mix design results for the virgin aggregate mix were within requirements for ISSA, LA County and ODOT standards for mix time and cohesion and met the requirements for wet track abrasion and loaded wheel testing. For mixes with RAP, the mix design with 10% asphalt emulsion fell short of the requirements for 1 hour cohesion, the 1-hour soak weight loss for wet track abrasion and lateral displacement, hence was not chosen for the final mix design. The RAP mix with 12% emulsion meets all the specifications except LA County's specification for slurry seal consistency. It is believed the additional emulsion helped meet specification requirements.

Despite having residual asphalt, the binder coating on the RAP samples may reduce cohesion and bond strength with the asphalt emulsion residue, hence a higher dosage is needed to satisfy the identified specifications. A longer curing time seems to remedy this condition, as seen in the 6-day soak test for the wet track abrasion; however, the failure to meet initial 1 hour soak time aggregate loss requirements does not permit the use of the RAP with 10% emulsion mix if a fast opening time to traffic is targeted. The cohesion test results further highlight the need for longer curing times for samples with RAP, since none of the RAP mixes met specifications for the 60-minute cohesive strength requirement of 20Kg-cm, once again potentially pointing to the existing binder that coats the RAP particles that inhibits early strength formation. A higher asphalt content in the mix design of RAP samples may remedy this but runs the risk of high sand adhesion values.

10 Field Study for Evaluation of Microsurfacing and Chip with RAP Constructed on Local Roadways in Ohio

10.1 Test Site Selection

The objective of the field study is to evaluate the construction and performance of chip seal and microsurfacing utilizing RAP as an alternative to virgin aggregate. The results of the literature search and interviews indicate the "waste" from processing RAP into aggregate for chip sealing can be used as aggregate for microsurfacing. Therefore, the research team recommends the field investigation consists of test sections using RAP as aggregate for chip sealing and RAP as aggregate for microsurfacing. Ideally RAP chip seal and RAP microsurfacing treatments are constructed from the same RAP stockpile to make the most use of the RAP, however, which treatments are placed in each agency is at the discretion of the local agency. Control sections constructed with virgin aggregates should be constructed for comparison.

As noted previously, RAP materials from two local agencies, City of Lancaster and Wayne County, were selected for the design of RAP microsurfacing and RAP chip seal, respectively. Additionally, virgin aggregate typically used for the respective treatment in each agency was also used for the development of virgin chip seal and virgin microsurfacing designs. Proposed test sections in Wayne County include a control (virgin) chip seal, and a RAP chip seal, placed by county forces. During the course of the research, the research team learned the City of Lancaster, in central Ohio, had been planning to place a RAP microsurfacing treatment and a RAP chip seal. While they plan to place both treatments, the RAP chip seal will be placed by city forces on alleyways. Due to the short length and difficulty in developing an adjacent control section, it is proposed only RAP and virgin microsurfacing treatments be evaluated for this study. Microsurfacing treatments placed in City of Lancaster would be placed by contract.

The locations of the proposed chip seal and microsurfacing test sites within Ohio are shown in Figure 10-1.

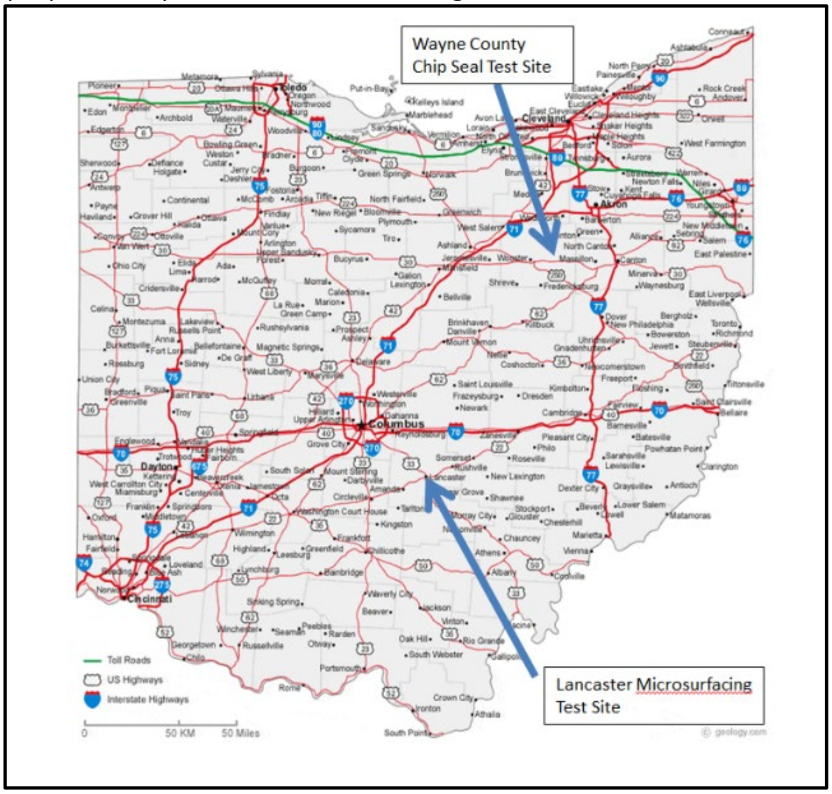


Figure 10-1 Test Section Locations

10.1.1 Chip Seal Test Site

In October 2020, the Wayne County Assistant Engineer provided a list of chip seal candidates, shown in Table 10-1 Wayne County Candidate Sections, for consideration as test sections.

Table 10-1 Wayne County Candidate Sections

Wayne County Roadway Sections							
County Road	**Name**	**ADT**	**Starting Point**	**End Point**	**Length**	**Current Treatment**	**Year**
Medium ADT, Non-Amish							
CR 6	Friendsville Road	909	TR108	Medina Co.	4.15	Chip Seal	2017
CR 51	Caanan Center Road	566	TR027 LT	Medina Co.	5.68	Chip Seal	2017
CR 502	Smucker, Chippewa, High St.	724	TR216	Orrville Corp.	2.83	Paved	2012
Medium ADT, Amish							
CR 54	Honeytown Road	643	CR501	CR030A	7.79	Chip Seal	2010
CR 142	Millborne	552	Apple Creek Corp.	CR030A	3.22	Paved	2012
CR 225	Criswell Road	549	Holmes Co.	TR165 LT	4.11	Paved	2001/2020
Low ADT, Non-Amish							
CR 139	Heyl Road	285	CR036	SR3	5.23	Chip Seal	2008/2011
CR 145	Chippewa	367	CR502/CR207	CR027	2.96	Chip Seal	2007/2014
CR 213	Bates Road	146	US250	CR161	5.00	Chip Seal	2008/2015
Low ADT, Amish							
CR 77	Moreland Road	344	CR054	CR187	4.39	Chip Seal	2001
CR 97	Wengerd Road	179	CR217	TR156	1.83	Chip Seal	2006/2007
CR 105	West Lebanon Road	302	US250	SR241	3.57	Paved	2006
CR 105	West Lebanon Road	302	SR241	TR334	2.70	Chip Seal	2003

Sections selected for the field investigation should be free of structural distress because chip seals and microsurfacing are preventive maintenance treatments not intended to correct structural issues. Due to COVID-19 pandemic travel restrictions, the research team was unable to visit all test sites to determine the condition of the pavement during the initial site selection. In lieu of the site visits, the research team viewed the sections on Google street view. Images on Google street view ranged in age from 10 years to 2 years. Sections with patching or wheel track cracking were eliminated from consideration.

The team also wanted to minimize the number of variables affecting the long-term performance of the test sections. The Amish community, which use horse and buggy for travel, use carbide studs on horse shoes for traction in the winter. These horse shoes damage the surface of the pavement so routes used by the Amish were not considered for test sections since this research is focused on the performance of these treatments on the local system statewide and not the ability of the treatment to resist a local distress issue.

Finally, straight and level sections were desired to eliminate geometrics and the associated distresses, i.e. edge cracking on the inside of curves, etc., as variables.

After eliminating sections based on the above criteria, the team identified three potential routes for the test section: CR 502 (Figure 10-2), CR 145 (Figure 10-3), and CR 213 (Figure 10-4). CR 502 (Smucker, Chippewa, and High Street) and CR 145 (Chippewa) intersect at Chippewa and Smucker (see Figure 10-5). This location was recommended for further consideration as the test site because it would allow the evaluation of chip seal with and without RAP aggregate on a route with low traffic and a route with medium traffic.

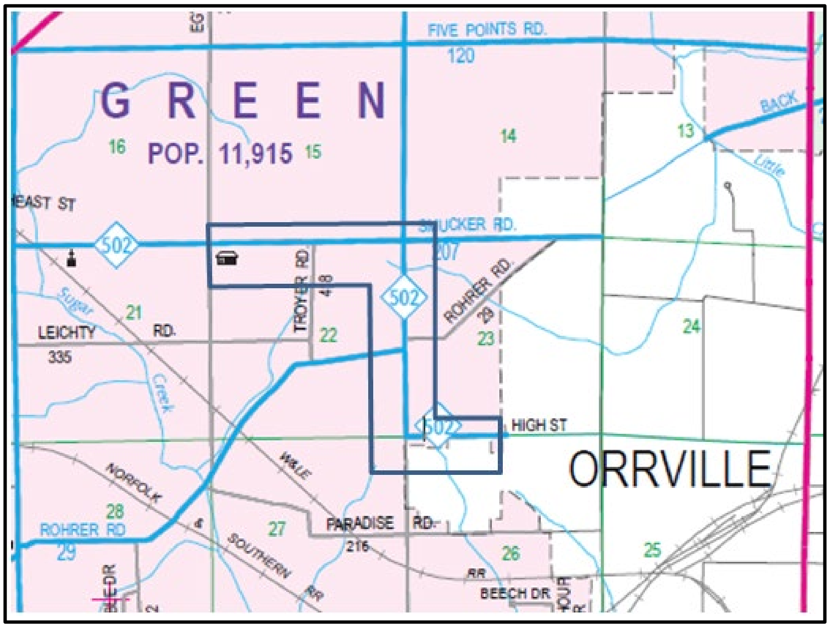


Figure 10-2 Wayne County CR 502

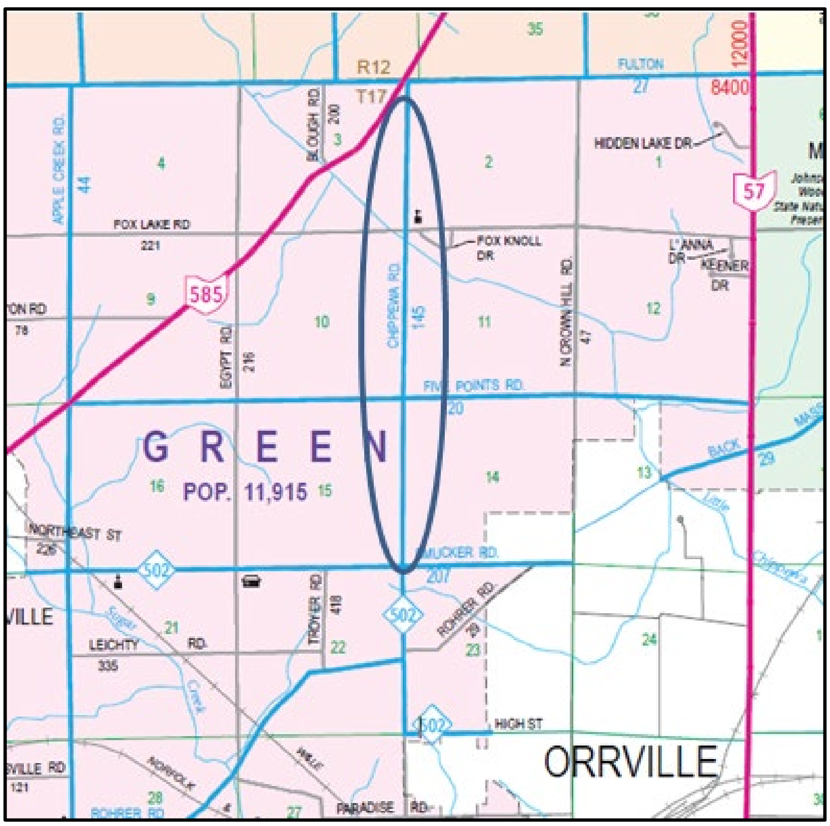


Figure 10-3 Wayne County CR 145

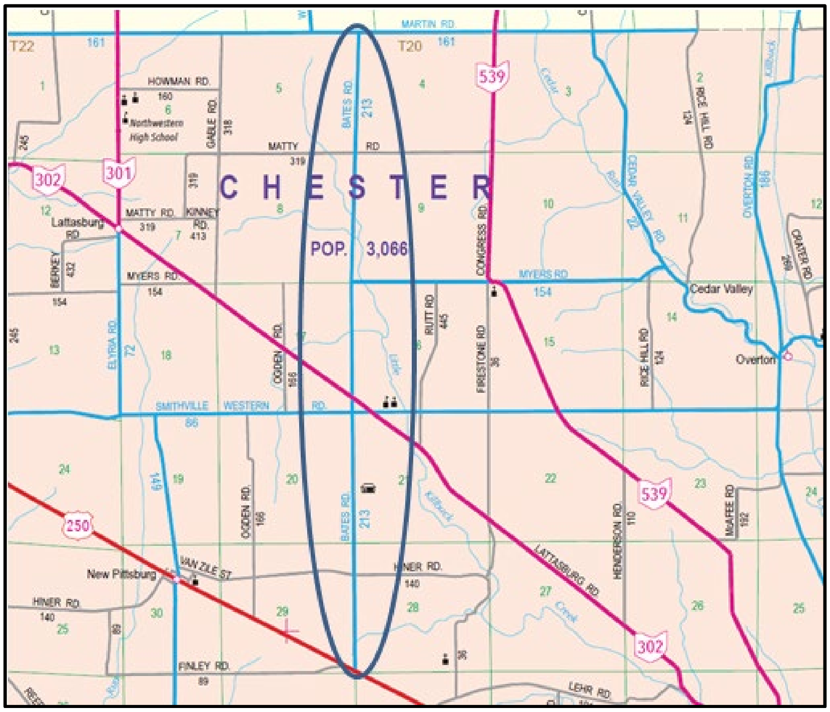


Figure 10-4 Wayne County CR 213

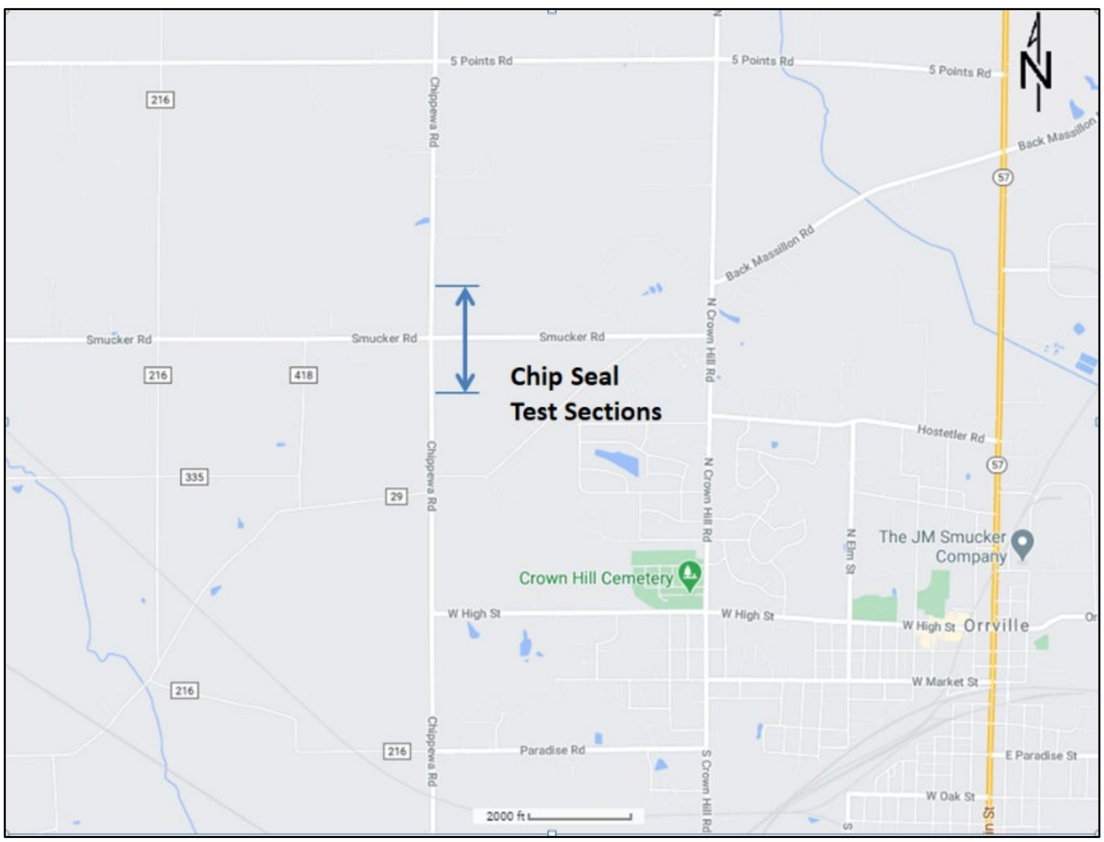


Figure 10-5 Wayne County Chip Seal Test Site

The potential chip seal test site, shown in Figure 10-5, is located on Chippewa Road at the intersection of Smucker Road. This location allows the evaluation of the treatment under two traffic volumes, 367 ADT north of Smucker Road and 724 ADT south of Smucker Road. Further evaluation of the site was conducted. At the time, COVID 19 travel restrictions allowed one person to travel to the test site which the Co-PI did on March 6, 2021. The section north and south of Smucker Road were similar in appearance with edge cracking throughout as seen in Figures 10-6 and 10-7. Minor rutting and uneven pavement north of the intersection was observed. Both sections appeared to have a chip sealed surface, see Figures 10-7 and 10-9. Although the section south of the intersection (between High Street and Smucker Road) was listed as paved in Table 10-1.

Figure 10-6 Chippewa between 5 Point Road and Smucker Road

Figure 10-7 Surface of Chippewa between 5 Point Road and Smucker Road

Figure 10-8 Chippewa between Smucker Road and High Street

Figure 10-9 Surface of Chippewa between Smucker Road and High Street

The research team, in consultation with the TAC, recommends the chip seal using RAP as an alternative to virgin aggregate be constructed in one direction (southbound) and the treatment using virgin aggregate be constructed in the opposite direction. The research team proposes 1000’ test sections for the “low” traffic volume and “medium” traffic volume test sections on Chippewa Road. It is proposed the RAP chip seal be placed in the southbound direction, and the virgin chip seal be constructed in the northbound lane, as summarized in Table 10-2. The research team has provided recommended chip and binder application rates in Section 8. Application rates were designed in Task 7 based on target RAP gradations developed in Task 6 and the gradation of the virgin aggregate provided to the team. The research team recommends the county construct test strips to verify the rates provided and make adjustments to application rates as needed.

Table 10-2 Proposed location of Chip Seal Test Sections

Agency	Road Name	Treatment	Direction	Location	Length (feet)	Traffic (ADT)	Aggregate Type
Wayne County	Chippewa	Chip Seal	SB	South of Smucker	1000	724	RAP
Wayne County	Chippewa	Chip Seal	SB	North of Smucker	1000	367	RAP
Wayne County	Chippewa	Chip Seal	NB	South of Smucker	1000	724	virgin
Wayne County	Chippewa	Chip Seal	NB	North of Smucker	1000	367	virgin

10.1.2 Microsurfacing Test Site

For this study, Wayne County will not be constructing any microsurfacing treatments. During Task 1, the research team learned the city of Lancaster planned to construct a microsurfacing test section with RAP aggregate in 2021. The city was willing to provide a test section for this research project.

The proposed microsurfacing test site, shown in Figure 10-10, is located on Whittier Drive between North Memorial Drive and Coldspring Drive. Whittier drive functions as a connector between North Columbus

Street and the commercial area on Memorial Drive. Therefore, traffic volumes are higher on Whittier Drive south of Columbus Street when compared to Whittier Drive north of Columbus Street. Traffic volumes were not available for Whittier Drive north of North Columbus Street at the time of development of this plan but will be obtained prior to construction. Traffic volumes between Memorial Drive and North Columbus Street were collected by the City of Lancaster in March of 2021. The traffic volume for Whittier between Schorrway Drive and North Columbus Street are shown in Table 10-3.

Figure 10-10 City of Lancaster Microsurfacing Test Site

Field site visits to the location conducted in April 2021 by the Co-PI revealed age related cracking on the section of Whittier Drive north of Columbus Street, as shown in Figures 10-11 and 10-12. On the section south of Columbus Street, minor transverse and longitudinal cracking was observed, as shown in Figures 10-13 and 10-14.

Figure 10-11 Whittier Drive, north of Columbus Street, facing south.

Figure 10-12 Whittier Drive, north of Columbus Street, pavement texture.

Figure 10-13 Whittier Drive, south of Columbus Street, facing north.

Figure 10-14 Whitter Drive, south of Columbus Street, pavement texture.

Similar to the chip seal test sections, it is recommended microsurfacing with RAP as an alternative to virgin aggregate be constructed in one direction (either northbound or southbound) and the treatment using virgin aggregate be constructed in the opposite direction. The research team proposes 1000' test sections for the test sections on Whittier Drive south of North Columbus Street, as summarized in Table 10-3. The "low" traffic volume section of Whittier Drive is approximately 310 feet long so the test section will be limited to this length.

Table 10-3 Proposed location of Microsurfacing Test Sections

Agency	Road Name	Treatment	Direction	Location	Length (feet)	Traffic (ADT)	Aggregate Type
Lancaster	Whittier	Microsurfacing	NB	South of Columbus St.	1000	3797	RAP
Lancaster	Whittier	Microsurfacing	NB	North of Columbus St.	310	Unknown	RAP
Lancaster	Whittier	Microsurfacing	SB	South of Columbus St.	1000	3797	virgin
Lancaster	Whittier	Microsurfacing	SB	North of Columbus St.	310	Unknown	virgin

The research team will provide microsurfacing mixture design results and recommendations based on ISSA test methods for the RAP and virgin microsurfacing developed in Task 7 based on target gradations of the RAP developed in Task 6 and the gradation of the virgin aggregate provided to the team. Since the work will be conducted by contract, it will be up to the City as how they wish to specify the RAP and virgin microsurfacing mixes. The research team recommends the City of Lancaster construct test strips to verify the JMF and make adjustments to application rates as needed.

10.2 Field Study Test Plan

A preliminary, proposed test plan for the field study is provided here. The objectives for the field study will be met via the following tasks:

10.2.1 Task 1. Evaluate condition of pavement prior to construction

The condition of the pavement upon which the treatment will be placed will impact the performance of the treatment. The condition of the road should be documented prior to the treatment, and after any pretreatment (i.e. patching, leveling, etc.) by the local agency, using the procedure for local roads in the ODOT "Pavement Condition Rating System" manual. Figure 10-15 is the rating form recommended for use for local roads.

Section: ________________

Log mile: ______to_________

Sta: _________ to_________

LOCAL

Date: __________________

Rated by: _______________

# of Utility Cuts ___________

PAVEMENT CONDITION RATING FORM

DISTRESS	DISTRESS WEIGHT	SEVERITY WT.*			EXTENT WT.**			DEDUCT POINTS***
		L	M	H	O	F	E	
RAVELING	10	0.3	0.6	1	0.5	0.8	1	
BLEEDING	5	0.8	0.8	1	0.6	0.9	1	
PATCHING	5	0.3	0.6	1	0.6	0.8	1	
SURFACE DISINTEGRATION or DEBONDING	5	0.3	0.6	1	0.6	0.8	1	
RUTTING	10	0.3	0.7	1	0.6	0.8	1 ✓	
MAP CRACKING	5	0.2	0.6	1	0.4	0.8	1	
BASE FAILURE	10	0.6	0.8	1	0.7	0.9	1 ✓	
SETTLEMENTS	5	0.4	0.7	1	0.6	0.8	1	
TRANSVERSE CRACKS	10	0.4	0.7	1	0.5	0.7	1 ✓	
WHEEL TRACK CRACKING	15	0.4	0.7	1	0.5	0.7	1 ✓	
LONGITUDINAL CRACKING	5	0.2	0.6	1	0.4	0.8	1 ✓	
EDGE CRACKING	5	0.4	0.7	1	0.5	0.7	1 ✓	
PRESSURE DAMAGE/UPHEAVAL	5	0.4	0.6	1	0.5	0.8	1	
CRACK SEALING DEFICIENCY	5	1	1	1	0.5	0.8	1	

*L = LOW **O = OCCASIONAL TOTAL DEDUCT =

M = MEDIUM F = FREQUENT SUM OF STRUCTURAL DEDUCT (✓) =

H = HIGH E = EXTENSIVE **100 - TOTAL DEDUCT = PCR =**

*** DEDUCT POINTS = DISTRESS WEIGHT X SEVERITY WT. X EXTENT WT.

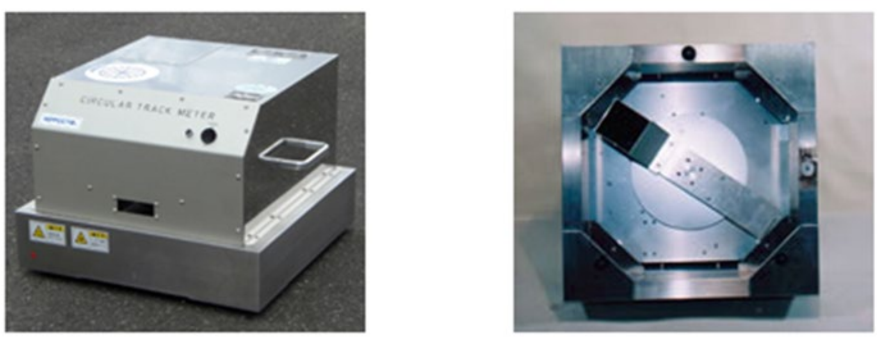
REMARKS:

Figure 10-15 Local System Pavement Condition Rating Form

During the pavement condition rating, the transverse profile of the pavement will be determined at a minimum of four locations using a FACE Dipstick 2200 profiler (Figure 2-2). The Dipstick measures the elevation from a reference point at one-foot intervals. These measurements will be used to determine cross slope and rutting.

Figure 10-16 FACE Dipstick 2200 profiler

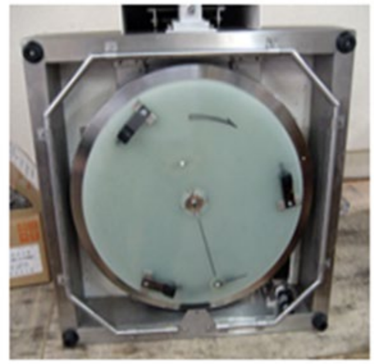
The effect of the treatments on the texture and skid number are also of interest. the surface friction number will be collected with the Dynamic Friction Tester (DFT) at the same locations the cross slope is measured. The research team recommends the use of the Circular Texture Meter (CT Meter) for characterizing the texture of the pavement. Photos of the CT Meter and the DFT are shown in Figures 10-17 and 10-18, respectively. Measurements should be made prior to construction of each test section at four locations, consistent with the longitudinal distances at which the FACE dipstick measurements are taken.



FRONT VIEW BACK SIDE

Figure 10-17 Circular Texture Meter (http://www.nippou.com/en/products/ct.html)

Main Body



Back Side

Figure 10-18 Dynamic Friction Tester (http://www.nippou.com/en/products/ct.html)

10.2.2 Task 2. Monitor construction process

The JMF and design applications rates used at the project site should be obtained from which pertinent mix design information can be collected. Prior to placement of each treatment, material application rates should be verified, as feasible. Construction should be monitored, and pertinent information collected, such as date, equipment condition and manufacturer/model, begin and end time for construction, air temperature, pavement temperature, humidity, binder temperature, distance between chip box and roller, roller passes, time to opening, etc. Hand mixing tests should be performed on collected field-produced microsurfacing mixture during construction. Hand mixing will provide important workability indicators and can be compared to hand mixing test results from the initial laboratory testing performed in Task 7.

Defects in the finished surface should be documented, e.g., streaking and ridges, bleeding/flushing, loss of cover aggregate, poor longitudinal joint, poor butt joint in chip seal; non-homogeneous mixture, poor longitudinal or transverse joints, poor butt joint, improper break time, tears and drag marks, etc. in microsurfacing. Pictures will be taken to document the construction process.

10.2.3 Task 3. Collect material samples

Sufficient amounts of aggregate and RAP should be obtained from the hopper of the microsurfacing equipment or the chip box to perform gradation and moisture tests. In addition, sufficient amounts of asphalt emulsion, mineral filler, and additives, if any, should be sampled and stored. Likewise, sufficient asphalt emulsion to perform a verification of the chip seal mix design should be sampled from the distributor and stored. These materials should be used to conduct verification testing if the initial performance of the treatment requires an analysis of the materials or JMF.

10.2.4 Task 4. Material and Construction Cost

Cost of material and construction for chip sealing should be obtained from the Wayne County Engineer and for microsurfacing from the city of Lancaster. A contractor will construct the microsurfacing in Lancaster. The bid documents for this work as well as the cost for aggregate and RAP processing should be obtained. Wayne county personnel will be used to construct the chip seal. The cost of virgin aggregate and the RAP processing cost should be obtained from the county engineer's office.

10.2.5 Task 5. Evaluate condition of pavement post construction

Immediately after construction, the condition of the road using the same procedures as Task 1 should be documented. The following monitoring procedures should be performed:

- Distress should be documented following procedure for local roads in the ODOT "Pavement Condition Rating System" manual.
- Cross slope and rutting should be measured at the same locations in Task 1 using the FACE Dipstick 2200 profiler.
- Texture should be measured at the same locations in Task 1 using the CT Meter
- Surface friction should be measured at the same locations in Task 1 using the DFT if roadway surface indicates friction is a concern (e.g. loss of aggregate or polished surface).
- Pictures should be taken to document the initial condition of the treatment.

10.2.6 Task 6. Develop Long-Term Monitoring Plan for Local Agency

Prior to construction of the test sections, a monitoring plan for the local agency to evaluate long-term performance and to collect information to support a life-cycle cost analysis (LCCA) should be developed. To complete the LCCA, the benefits of the treatment, in terms of performance, and cost are needed.

The research team recommends the performance of the treatment be monitored using the pavement condition rating (PCR) determined annually using the procedure described in Task 1.

Costs for LCCA include construction cost as well as maintenance cost, if any, during the service life of the treatment. Material and construction costs should be gathered during task 4.

10.2.7 Task 7. Prepare report

The work performed in Task 1 through Task 4 should be documented for future use of RAP in chip seal and microsurfacing by local agencies.

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12 Appendix A: Questionnaire for Practitioners Using RAP in Pavement Preservation Treatments

Name:
Agency/Company:
Title:
E-mail:
Phone Number:

The purpose of this survey is to reach out to agencies and companies that have experience placing preventive maintenance/ preservation treatments with RAP. You have been identified as a knowledgeable source for this information and we would like to synthesize your experience with other pavement maintenance professionals in the US to determine those practices that have produced successful preventive maintenance/ preservation treatments with RAP.

I would like to thank you in advance for your support for this interview. This project's results will furnish a means to disseminate the experience of maintenance engineers from the US in a very straightforward fashion. Thank you for your time and information.

If you have had experience designing or constructing pavement preservation treatments (chip seal, scrub seal, slurry seal, microsurfacing or Otta seal) with RAP, please complete the following questionnaire. If you have not, thank you for your time. If we have reached you in error, please let us know so we may find the appropriate contact or you may pass it on to the appropriate personnel within your agency if known.

Mary Robbins, Ph.D.

General

1. Have you had any experience designing or constructing chip seal, microsurfacing, scrub seal, slurry seal, or Otta seal with RAP?
    a. If yes, which treatment(s)?
    b. How long have these treatments been in service?
    c. Did you have any issues during design, construction, or while in service?
    d. How does the performance of these treatments compare with their non-RAP counterpart?
2. How did you hear about using RAP in preservation treatments (original idea, read about, contractor suggested, heard about from another agency [who?])
3. What are the advantages and disadvantages of using RAP in chip seal, slurry seal, microsurfacing, or Otta seal?
4. How does the cost compare to conventional chip seal, scrub seal, slurry seal, microsurfacing, or Otta seal treatments?
5. What percentage of chip seals, scrub seal, slurry seal, microsurfacing, or Otta seals utilize RAP?
6. Were there construction materials specifications for these treatments and conventional treatments?
    a. How do they differ from conventional chip seal, scrub seal, microsurfacing, slurry seal, or Otta seal?
    b. Could you please provide specifications or plan notes for the conventional treatments and treatments using RAP?
7. How does quality control/quality assurance (i.e. material acceptance testing, calibration, verifying rates, verifying aggregate properties, etc.) for mixes with RAP differ from conventional chip seal, slurry seal, microsurfacing, or Otta seal treatments?
    a. Are QA/QC samples collected? If so, what types of samples and how often?
    b. Are QA/QC tests conducted? If so, what tests and how often?
8. Has your use of RAP in chip seal, scrub seal, slurry seal, microsurfacing, or Otta seal treatments been researched and/or documented? If so, please provide the reference(s).

9. Can you provide the name and contact information for contractors who have constructed pavement preservation treatments (other than HMA) using RAP for your agency?
10. Can you provide the name and contact information for material suppliers for the pavement preservation treatments (other than HMA) for your agency?

Mix Design

1. How does mix design or application rates differ (i.e. higher or lower emulsion rate, higher or lower aggregate rate) from conventional chip seal, scrub seal, slurry seal, microsurfacing, or Otta seal treatments?
2. What type of bituminous material was used for the chip seal (e.g. hot applied binder, emulsified asphalt, polymer modified emulsion, or cutback asphalt)?
3. What type (e.g. cationic, anionic, CRS, CSS, CQS, PG 64-22, etc.) of emulsion or binder is utilized for chip seal with RAP, scrub seal with RAP, microsurfacing with RAP, slurry seal with RAP, and Otta seal with RAP?
    a. Have you had any issues with compatibility?
    b. Do you use modifiers with your base asphalt or binder?
4. What is the amount (e.g. 0-25%, 25-50% RAP, 50-75% RAP, 75-100% RAP, etc.) of RAP usage in these treatments?
    a. How was this ratio determined?
5. Do you have any approved job mix formulas (JMFs) for chip seals, scrub seals, slurry seals, microsurfacing, or Otta seals with RAP, you would be willing to share with us?

RAP Characterization

1. How was the RAP characterized, or what properties of the RAP were required (e.g. gradation, sand equivalence, soundness, etc.) for the preservation treatment? [Provide specification if possible]
2. Was RAP processing or additional fractionation required to meet gradation requirements for the preservation treatment(s)?
    a. If so, what was done to meet requirements?
3. If so, what is an estimated cost of the additional processing to meet gradation requirements of the preservation treatment(s)?
4. What are the sources of your RAP (e.g. pavement milling operations (cold planing), full-depth pavement demolition and/or wasted asphalt plant mix)?
    a. Is the source for the preservation treatment different than other applications (e.g. HMA)?
5. Who owns the RAP stockpile? Who controls what millings are placed in the stockpile?
6. Is any testing routinely conducted on RAP stockpiles? If so, which tests?
7. Is the RAP typically fractionated into stockpiles for different sizes?
    a. If so, how is the RAP fractionated (what are the sizes)?
    b. What is the added cost of the fractionation process ($/ton)?
8. What are some of the disadvantages of fractionation?
9. For LA County: Your specification for Polymer Modified Emulsified Asphalt-Reclaimed Asphalt Pavement Aggregate Slurry Seal (PMERAPAS) (908) requires RAP conform to 203.7.2.2 and those in Table 908-2.2.1. We were unable to find 203.7.2.2 in your specifications or in the Green Book. Could you please provide us with those specifications?
10. For LA County: How were your specifications developed? By adjusting specs for non-RAP treatments? Based on recommendations from industry/contractors?

Is there anything that you would like to add that was not covered in this questionnaire that you feel would benefit this study?

Thank you very much for your contribution. You will be sent a link where you can download a free copy of the completed research work when it is completed. In the meantime, feel free to give me a call if you have questions on this subject.

Mary Robbins, PhD
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13 Appendix B: Assessment of RAP Supply in Ohio

13.1 Ohio Asphalt Producers Phone Interviews/Questionnaire

A sample of large asphalt producers in Ohio were selected from which to obtain information related to stockpiling of RAP. A questionnaire was developed and sent to representatives of seven of the largest asphalt producers in the states. Three asphalt producers responded, which combined have plants in all four regions of Ohio. At the request of the producers, the names of the representatives and the asphalt producers they represent have been kept anonymous. The questionnaire is provided in section 13.1.2. While the questionnaire was meant to provide the asphalt producer with type of information sought during the requested phone interview, one producer elected to complete the questionnaire via email, the other two participated in a phone interview. Given the sensitivity of the questions, the amount of the questionnaire that was completed or responses provided in the phone interviews varied by producer. Key points from the phone interviews/questionnaire are summarized in the following subsection.

13.1.1 Ohio Asphalt Producers Phone Interview/Questionnaire Summary

In Ohio, the contractor (associated with or owner of the asphalt producer) retains the pavement millings unless otherwise stated in the contract documents or plans. Via phone interviews or the completion of the questionnaire via email, the asphalt producers indicated the overall percentage of RAP that is retained by agencies (local or state) is small.

RAP may be generated from millings of state or local roadways or from milling commercial property (e.g., parking lots). RAP generated from pavement millings was reported to make up the majority (70% or more) of the RAP the asphalt producers obtain, with other sources including full depth pavement repair or removal, parking lot milling or removal, and asphalt plant waste.

Regarding the amount of RAP available, two producers responded with estimates of RAP stockpiled as of January 1, 2019 ranging from 600,000 tons to 1.5 million tons across all plants. One of the two producers indicated the amount of RAP acquired in 2019 was hard to estimate but was on par with previous years. The third producer identified ODOT as the largest producer and user of RAP and the amount of RAP available is tied to the amount of money available for construction and the number of projects awarded, as money available for paving projects fluctuates, so does the RAP supply. The producer also identified other issues that may impact the amount of RAP available including the increase in the gas tax in Ohio which would result in increased revenues and construction dollars available for paving projects, while the recent coronavirus pandemic caused some large projects to be delayed and may result in a decrease in RAP availability and HMA/WMA production.

The limitations on RAP and minimum virgin binder content in ODOT specifications prevent RAP from being used at the same rate HMA/WMA is produced. To this end, RAP was reported to be abundant and excessive relative to what is needed for HMA/WMA. Two producers indicated there is more than enough RAP available for use in HMA/WMA production. Both of which reported RAP being stockpiled for 5 to 6 years without being used. One of the two producers stated approximately 60% of the RAP retained does not get used, although the amount used is dependent on the type of HMA/WMA being produced. The third producer indicated RAP may be stored for 1 to 2 years.

Although RAP was reported to be in excess overall, one producer stated the excess is tied to urban areas where the restoration of curb and gutter, and where the intersection of interstate routes generate abundant pavement millings. While they reported excess RAP in urban areas, their plants in rural counties may be void of RAP or experience surges in RAP supply. The cost of hauling RAP from urban areas where RAP is abundant to rural areas where there is little to no RAP available is prohibitive, as a result, production of HMA/WMA in rural areas may done with little to no RAP.

In areas where RAP supplies are in excess, the asphalt producers indicated they will either store or sell additional RAP. Two producers indicated there was no additional cost related to storing excess RAP. It was reported RAP is sold infrequently, with one producer indicating the rate is often slightly greater than the cost of virgin aggregate, while the other two reported rates of $20-25 per ton and $50 per ton for pickup from the plant or "FOB price." One producer indicated their rate of $20 - $25 per ton would include some processing of the RAP.

Regarding the processing that is completed on RAP, one indicated large chunks of millings are processed to ½" to 1" size. Another producer also indicated large chunks are processed from pavement removals, where the pavement was not milled. It was implied this processing included screening and crushing of the RAP. Costs for processing were reported as $1 to $4 per ton and $3.50 to $4.50 per ton. One producer indicated some plants are equipped with in-line processing equipment, but generally some amount of processing is completed prior to introduction to the plant, unless the project which generated the millings was a "mill and fill". They also indicated fractionation may be conducted but works best when the plant has more than one cold feed bin. Two producers reported that when fractionation is conducted, the top size used for surface and intermediate mixes is 9/16 inch (14.29 mm) and 1 inch (25.4 mm) for base mixes. One of the two also reported a top size of 2 inches (50.8 mm) was used for berm material. One producer reported a cost of fractionation at $3.50 per ton, which is on par with the reported costs for processing RAP from the other two producers. While consistent gradation and asphalt content were reported as advantages of fractionation of the RAP, the cost to do so was cited as the disadvantage.

Two producers provided some information related to storage of the RAP such that RAP is stockpiled by the project from which they were generated to meet ODOT requirements. One of the two producers indicated steps to prevent contamination of the stockpiles are taken such as sampling and testing the RAP for approval and then staking the stockpile. They also reported contaminated stockpiles may be used for berm material. All three producers reported routine testing on the RAP includes gradation, moisture content, and asphalt content. One producer indicated they have also conducted sodium soundness tests on RAP in the past and have never encountered RAP that does not meet ODOT requirements for virgin aggregate.

13.1.2 Ohio Asphalt Producers Phone Interview/Questionnaire

Name: ________________________________

Agency/Company: ________________________

Title: ___________________________________

E-mail: __________________________________

Phone Number: ___________________________

RAP Sources

1. Did you accept, process, or use RAP in the state of Ohio in 2019?
    a. ___Yes
    b. ___No
2. Approximately how many tons of RAP did you have stockpiled on January 1, 2019
    a. ___ tons
3. Approximately how many tons of RAP was acquired in 2019?
    a. ___ tons
4. How does total amount of RAP compare to years past? Please provide the approximate percent change:
    a. __ % increase
    b. __ % decrease
    c. __ about the same
5. How much RAP (tons) was stockpiled at the end of 2019 at each facility (plant/yard)?
    a. _________________tons or CY
6. Where does the RAP come from?
    a. ___% or tonnage pavement millings
    b. ___% or tonnage full depth pavement removal
    c. ___% or tonnage asphalt plant waste
    d. ___% or tonnage purchased from others
7. Ignoring the effects of the current COVID-19 pandemic, do you expect the amount of RAP to increase, decrease, or remain the same in near future?
    a. __ increase
    b. __ decrease
    c. __ stay about the same
8. What are the reasons for the projected trend in question 7?
    a. _____________________________________
9. Approximately what percentage (or tonnage) of RAP from **pavement millings** was used in each application?
    a. ___% or tonnage HMA
    b. ___% or tonnage Granular base
    c. ___% or tonnage Fill
    d. ___% or tonnage Shoulder/berm
    e. ___% or tonnage Cold central plant recycle mix
    f. ___% or tonnage Landfill
    g. ___% or tonnage Other:____________________________________
10. How were pavement millings processed prior to use?
    a. _______________________________________
11. Approximately what percentage (or tonnage) of RAP from **full depth repair** was used in each application?
    a. ___% or tonnage HMA

    b. ___% or tonnage Granular base
    c. ___% or tonnage Fill
    d. ___% or tonnage Shoulder/berm
    e. ___% or tonnage Cold central plant recycle mix
    f. ___% or tonnage Landfill
    g. ___% or tonnage Other:_____________________________________

12. How was the RAP from full depth repairs processed prior to use?
    a. ____
13. Approximately what percentage (or tonnage) of RAP from **asphalt plant waste** was used in each application?
    a. ___% or tonnage HMA
    b. ___% or tonnage Granular base
    c. ___% or tonnage Fill
    d. ___% or tonnage Shoulder/berm
    e. ___% or tonnage Cold central plant recycle mix
    f. ___% or tonnage Landfill
    g. ___% or tonnage Other:_____________________________________
14. How was the RAP from asphalt plant waste processed prior to use?
    a. ____
15. Approximately what percentage (or tonnage) of RAP from **others** was used in each application?
    a. ___% or tonnage HMA
    b. ___% or tonnage Granular base
    c. ___% or tonnage Fill
    d. ___% or tonnage Shoulder/berm
    e. ___% or tonnage Cold central plant recycle mix
    f. ___% or tonnage Landfill
    g. ___% or tonnage Other:_____________________________________
16. How was the RAP from other sources processed prior to use?
    a. ____
17. Approximately how much RAP was obtained from milling projects in 2019?
    a. ___tons State projects (millings)
    b. ___tons Municipal/County projects (millings)
18. Are different sources (projects) of RAP kept separate or are they combined?
    a. __Separate
    b. __Combined
19. If combined, what testing is conducted on the blended stockpile?
    a. ___________________________
20. If not combined, what is the reason (not enough space in the yard, prohibited by state or local specs, etc.)?
    a. ___________________________
21. Do you, or would you be willing to sell RAP?
    a. ___Yes
    b. ___No
    c. ___Not sure
22. If yes, what is the current price per ton (FOB plant)?
    a. _________$/ton

RAP Amount/Storage

1. How do you determine how much RAP to stockpile?
    a. ______________________________________
2. How much RAP is used each year?
    a. _________________tons or CY
3. How does the amount of RAP from pavement millings stockpiled for the next year compare to years past?
    a. __ % increase
    b. __ % decrease
    c. __ about the same
4. Do you expect an increase or decrease RAP stockpiled from pavement millings in the future, and why?
    a. Increase, because: _________________
    b. Decrease, because: ________________
    c. Stay the same, because: _____________
5. Typically, how long is RAP typically stored?
    a. __________
6. What percentage of RAP is wasted and what is done with it?
    a. ___%
7. What are some reasons a RAP stockpile would be disposed of?
    a. ____
8. Is any RAP returned to the owner (ODOT, municipality or county)?
    a. ____
9. What constitutes a contaminated stockpile and what is done with contaminated stockpiles?
    a. ____
10. What steps are taken to prevent contamination of the stockpile?
    a. ____

RAP Processing

1. If RAP is fractionated, what size fractionation is used for each application?
    a. HMA: _______________
    b. Granular base: ____________
    c. Fill: _______________
    d. Shoulder/berm: ___________
    e. Cold central plant recycle mix: _______________
    f. Other (please list): __________________________________
2. What is the cost of fractionating RAP ($/ton)?
    a. ________$/ton
3. What are some of the advantages/disadvantages of fractionation (e.g. agglomeration of fines?)
    a. Advantages: _____________________________________
    b. Disadvantages: ___________________________________
4. What is the approximate cost of transporting RAP ($/ton/mile)?
    a. ______________$/ton/mile
5. What is the approximate cost of storing RAP each year ($/ton/year)?
    a. ______________$/ton/year
6. Has the need for space for storing RAP resulted in additional costs, if so, how much ($/SY)?
    a. __Yes: ___________$/SY
    b. __No

7. Do you have gradation results (for fractionated or non-fractionated stockpiles) that could be shared with us?
    a. __Yes
    b. __No

RAP Quality Control

1. What testing is routinely conducted on RAP stockpiles (e.g. gradation, moisture, etc.)?
    a. ___________________________________
2. How frequently (X tons) is RAP sampled and tested?
    a. ___________________________________
3. What properties (extracted gradation, asphalt content, % passing X sieve, etc.) are used to control variability and what are the limits for each?
    a. __________________________________

13.2 RAP Supply of Local Agencies

13.2.1 RAP Supply, Summary of Findings from Survey and Phone Interviews with Local Agencies

An online survey was issued through the Local Technical Assistance Program's (LTAP) email list to gather information related to the storage and use of RAP at the county level. The survey was deployed on the Qualtrics platform, with survey questions and responses presented in the following subsections. A total of 18 agencies responded to the survey; their responses are tabulated in one of the following subsections.

In addition to the survey, phone interviews were conducted with selected counties. The research team understood that some local agencies stockpile RAP themselves. While the research team had knowledge of at least one agency, it was believed far more do so. Therefore, the research team utilized Google maps satellite map views to assess whether RAP stockpiles were visible at each of the 88 county engineers' yards around the state, from which a preliminary list was developed, listed in the table below. Counties were selected for follow-up phone interviews based on the likelihood they stockpile RAP and based on the results of the survey of local agencies regarding their RAP supply and usage and based on results from a second survey of local agencies regarding aggregates used for pavement preservation treatments. As shown in the map below, eight counties were selected for phone interviews representing all regions of the state. The intent was to select agencies that may stockpile RAP or indicated they do so in the survey or have been helpful in the past in providing information related to chip seal and/or microsurfacing treatments. The follow-up phone interviews sought to gather information related to RAP usage as well as information related to placement of microsurfacing and chip seal treatments, with heavier focus on microsurfacing as agencies responded with more information on chip seals than microsurfacing in the second survey on chip seals than microsurfacing. Auglaize county was selected based on past research projects in which it was revealed they stockpile RAP, and Butler county was selected based on previous preservation treatment test sections they had placed to study chip seal, cape seal and microsurfacing treatments.

Table 13-1 Preliminary List of Counties Possibly Stockpiling RAP

COUNTY NAME	RAP STOCKPILE	COUNTY NAME	RAP STOCKPILE
Adams County	maybe	Licking County	maybe
Allen County	no	Logan County	maybe
Ashland County	no	Lorain County	no
Ashtabula County	no	Lucas County	maybe inside shelter
Athens County	yes	Madison County	maybe

COUNTY NAME	RAP STOCKPILE	COUNTY NAME	RAP STOCKPILE
Auglaize County	yes	Mahoning County	yes
Belmont County	yes	Marion County	maybe inside shelter
Brown County	yes	Medina County	maybe inside shelter
Butler County	no	Meigs County	yes
Carroll County	yes	Mercer County	maybe
Champaign County	no	Miami County	maybe inside shelter
Clark County	maybe	Monroe County	yes
Clermont County	yes	Montgomery County	maybe inside shelter
Clinton County	yes	Morgan County	yes
Columbiana County	yes	Morrow County	no
Coshocton County	no	Muskingum County	yes
Crawford County	yes	Noble County	yes
Cuyahoga County	no	Ottawa County	maybe inside shelter
Darke County	yes	Paulding County	maybe
Defiance County	maybe	Perry County	yes
Delaware County	no	Pickaway County	maybe
Erie County	no	Pike County	no
Fairfield County	no	Portage County	yes
Fayette County	yes	Preble County	maybe
Franklin County	yes	Putnam County	maybe inside shelter
Fulton County	maybe	Richland County	maybe inside shelter
Gallia County	yes	Ross County	maybe
Geauga County	yes	Sandusky County	maybe inside shelter
Greene County	yes	Scioto County	maybe
Guernsey County	yes	Seneca County	yes
Hamilton County	maybe	Shelby County	no
Hancock County	no	Stark County	yes
Hardin County	yes	Summit County	maybe inside shelter
Harrison County	no	Trumbull County	YES
Henry County	no	Tuscarawas County	YES
Highland County	yes (inside shelter)	Union County	no
Hocking County	yes	Van Wert County	maybe inside shelter
Holmes County	yes	Vinton County	maybe inside shelter
Huron County	yes	Warren County	yes
Jackson County	yes	Washington County	yes
Jefferson County	yes	Wayne County	yes in several twp garages
Knox County	maybe	Williams County	yes
Lake County	yes	Wood County	maybe
Lawrence County	yes	Wyandot County	maybe inside shelter

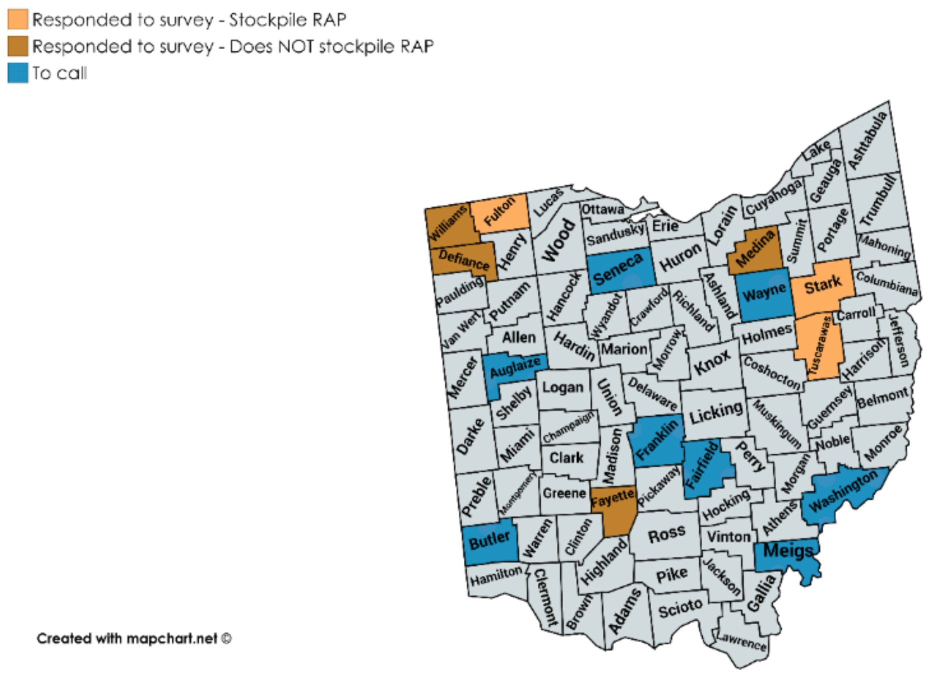

Figure 13-1 Map of Survey Respondents (Counties) and Identification of Counties for Phone Interviews

The research team attempted to contact all eight counties shown in blue on the map, however, Franklin, Meigs, Seneca and Wayne Counties did not respond. Through the phone interview with Fairfield County, it was revealed City of Lancaster (located in Fairfield County) may stockpile RAP and is progressive in using RAP in various ways. Therefore, City of Lancaster was also contacted.

As noted, the intent of the phone interviews was to gather additional information on the use and storage of RAP and information related to aggregates used in pavement preservation treatments (chip seal and microsurfacing). The questions for the phone interview are presented in a later section, however the first half of the phone interview focused on RAP usage and storage, therefore responses from the agencies that indicated in the phone interview that they stockpile RAP are summarized in this section with the results from the survey. Responses to the second half of the phone interview questions regarding aggregates used in pavement preservation treatments are summarized with those survey results.

Including agencies with which phone interviews were conducted, and those that responded via the online survey (including incomplete surveys), a total of 22 agencies responded. The majority of the responding agencies were counties (15), followed by townships (5) and cities (2).

Regarding the availability of RAP, six agencies indicated they had purchased RAP in the past, with prices ranging from $5/ton to $25/ton. One agency indicated the RAP they purchased was asphalt waste and was $10/ton to $12/ton, they also indicated they would like to purchase RAP (millings) but it is hard to come by. Participants were also asked how much pavement planing in square yards (SY) is conducted each year. The majority (13 agencies) responded that pavement planing was done, while one did not provide an amount, 12 did, with broad ranges. The smallest quantity listed was 1,000 SY, while the largest was

200,000 SY. Seven agencies reported values between 25,000 and 50,000 SY. Some agencies provided an estimate in miles (3 to 4 miles, and 15 miles) while another provided an estimate in tons (600 tons).

Agencies were asked to report how much RAP was stockpiled in 2019 and how that RAP is used. Sixty percent (60%) of those responding to the question reported they had stockpiled RAP in 2019, with the amount stockpiled distributed evenly among the 4 ranges from which the agency could choose from, as described below.

- < 500 tons: 2 responses
- 500 – 1000 tons: 3 responses
- 1000 – 1500 tons: 3 responses
- > 1500 tons: 3 responses

Auglaize county reported 3000 tons had been acquired in 2019 (their response is included in the > 1500 tons range above) and that it is not uncommon to carry 500 to 600 tons of RAP to the next year. The City of Lancaster did not report a range but did report they have a stockpile of approximately 7000 tons that had been accumulated over the last couple of years, and they had been planning to use the RAP for chip seal and microsurfacing treatments. While City of Lancaster can be considered an urban area, many of the agencies that reported some amount of RAP was stockpiled in 2019 are rural counties, including the counties of Ashland, Auglaize, Crawford, Fulton, Huron, Tuscarawas, and Wayne.

For agencies which reported how their RAP was acquired, all but two indicated 100% of the RAP acquired in 2019 came from pavement millings. One agency reported 50% came from pavement millings and 50% from full depth pavement removal. Another agency reported of their RAP acquired in 2019, 20% came from county projects including milling and reconstruction, 40% came from contractors (which was mostly driveways and parking lot replacement), and the remaining 40% came from county projects including road repairs, storm sewer crossing, etc.

Agencies were asked to report how much RAP was used in HMA, granular base, fill, shoulder/berm, cold central plant recycle mix, chip seal aggregate, and aggregate road surfacing in 2019. Shoulder or berm was reported the most frequently with 6 agencies reporting amounts from 60 to 1500 tons, and one reporting it was used but not providing an amount. Two agencies reported the use of RAP for HMA, one of which indicated it was used in pothole repair. The other reported later in the survey the primary application of RAP pavement millings was in intermediate asphalt course. It is unclear if Medina County produces their own HMA. RAP for granular base and aggregate road surfacing each had two responses and one agency reportedly used RAP to repair roadway cuts for storm sewers and widening projects. City of Lancaster reported they had active plans to use RAP for chip seal and microsurfacing, although had not done so yet, and hoped to use RAP for cold central plant recycle in the future.

When asked about the processing of their RAP stockpiles for each application, four agencies responded regarding use for shoulder/berm. Two reported no processing of the RAP, one reported crushing/grinding and screening/fractionation is done, while the fourth agency reported only crushing/grinding. One agency responded that no processing was conducted when used in fill. When used as aggregate road surfacing, one agency reported crushing/grinding and screening/fractionation of the RAP. Lastly, City of Lancaster reported RAP would be processed to achieve chip seal and microsurfacing gradation with the target chip seal gradation a No. 8.

Agencies were also asked to report whether a contractor or the agency processes the RAP and the approximate cost to process RAP for each application. Four agencies indicated processing was completed by someone else, while one indicated they rent the equipment and process themselves. Little cost information was provided, however rates of $2/ton and $3/ton were reported for shoulder/berm, and repair roadway cuts, respectively.

13.2.2 Survey of Local Agencies Questions

Project: Design of Microsurfacing and Chip Seal Mixes with RAP for Local Roadway Application

Sponsored by: Ohio Research Initiative for Locals (ORIL)

Thank you for your willingness to participate in our survey. As part of this research study we are asking local agencies to provide information regarding the amount of RAP they store and use. If you have any questions regarding this survey you may contact the lead researcher, Mary Robbins, Ph.D., at robbinm1@ohio.edu. Thank you for your time.

Participant's information

Agency:

Name:

Position:

Phone Number:

Email Address:

General

Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?

Have you ever purchased RAP?

Yes

No

What was the average cost of RAP in $/ton?

About how much RAP did your jurisdiction stockpile in 2019?

We do not stockpile RAP

< 500 tons

500 - 1,000 tons

1,000 - 1,500 tons

> 1,500 tons

For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?

Pavement millings	0 %
Full depth pavement removal	0 %
Other:	0 %
Total	0 %

RAP Survey

How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change.

	% increase	% decrease	About the Same
a. Total tonnage:			
b. Pavement millings:			
c. Full depth pavement removal:			
d. Other:			

Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.

	% increase	% decrease	About the same
a. Total tonnage:			
b. Pavement millings:			
c. Full depth pavement removal:			
d. Others:			

Reason for the change in the previous question, if any?

No change

Pavement millings:

Full depth pavement removal:

Other:

Approximately how much RAP (tons) was used in each application in 2019?

	Amount (tons)
HMA:	
Granular base:	
Fill:	
Shoulder/berm:	
Cold central plant recycle mix:	
Chip Seal Aggregate:	
Aggregate Road Surfacing:	
Stockpiled for the next year:	
Other:	

What is the primary application for RAP pavement millings?

Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?

Yes

No

Sometimes

How is RAP processed for each application?

HMA:

Granular base:

Fill:

Shoulder/berm:

Cold central plant recycle mix:

Chip Seal Aggregate:

Aggregate Road Surfacing:

Other:

If RAP is fractionated, what are the sizes of fractionation?

If RAP is fractionated, who performs the fractionation?

What is the estimated cost of processing RAP for each application used in your jurisdiction?

	Cost ($/ton)
a. HMA:	
b. Granular base:	
c. Fill:	
d. Shoulder/berm:	
e. Cold central plant recycle mix:	
f. Chip Seal Aggregate:	
g. Aggregate Road Surfacing:	
e. Other:	

How long is RAP typically stored?

0 - 6 months

7 - 12 months

1 - 3 years

4 - 6 years

> 6 years

What percentage of RAP is wasted and how is it disposed?

What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?

Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?

Yes

No

Which tests are conducted on your RAP stockpiles? Select all that apply.

Binder content

Gradation of RAP

Gradation of extracted aggregate

Moisture content

Can we obtain a copy of the results from any testing conducted on RAP stockpiles? Or if you wish, please send it via email at robbinm1@ohio.edu .

What is the approximate cost of storing RAP each year ($/ton/year)?

13.2.3 Survey of Local Agencies Responses

Completed surveys

Question	Response #1	Response #2	Response #3	Response #4	Response #5
Agency type	County	County	Township	County	County
Agency:	Tuscarawas County	Stark County Engineer's Office	Rutland Township	fayette county	Defiance County
Name:	Joe Bachman	Jason Manson	Opal Dyer	Steve Luebbe	Warren Schlatter
Position:	County Engineer	Assistant Highway Engineer	Fiscal Officer	engineer	County Engineer
Phone Number:	3303396648	330-477-6781	740-742-2805	7403351541	419-782-4751
Email Address:	tcejoe@yahoo.com	jpmanson@starkcountyohio.gov	o_dyer@yahoo.com	steve.luebbe@fayette-co-oh.com	dce@defiance-county.com
Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?	1000	200,000 sy	0	very small amount. just to cut butt joints at limits and bridges.	0
Have you ever purchased RAP?	Yes	No	No	No	No
What was the average cost of RAP in $/ton?	$10	we don't buy it we get it from our resurfacing jobs			
About how much RAP did your jurisdiction stockpile in 2019?	1,000 - 1,500 tons	1,000 - 1,500 tons	We do not stockpile RAP	We do not stockpile RAP	We do not stockpile RAP
For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?					
- Pavement millings	100	100	0	0	0
- Full depth pavement removal	0	0	0	0	0
- Other:	0	0	0	0	0
- Other: - Text					
How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change					
- a. Total tonnage: - % increase	100				
- a. Total tonnage: - % decrease					
- a. Total tonnage: - About the Same					x
- b. Pavement millings: - % increase	100				
- b. Pavement millings: - % decrease					
- b. Pavement millings: - About the Same					x
- c. Full depth pavement removal: - % increase					
- c. Full depth pavement removal: - % decrease					
- c. Full depth pavement removal: - About the Same					x
- d. Other: - Text					
- d. Other: - % increase					
- d. Other: - % decrease					
- d. Other: - About the Same					

Question	Response #1	Response #2	Response #3	Response #4	Response #5
	Completed surveys				
Agency type	County	County	Township	County	County
Agency:	Tuscarawas County	Stark County Engineer's Office	Rutland Township	fayette county	Defiance County
Name:	Joe Bachman	Jason Manson	Opal Dyer	Steve Luebbe	Warren Schlatter
Position:	County Engineer	Assistant Highway Engineer	Fiscal Officer	engineer	County Engineer
Phone Number:	3303396648	330-477-6781	740-742-2805	7403351541	419-782-4751
Email Address:	tcejoe@yahoo.com	jpmanson@starkcountyohio.gov	o_dyer@yahoo.com	steve.luebbe@fayette-co-oh.com	dce@defiance-county.com
Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.					
- a. Total tonnage: - % increase					
- a. Total tonnage: - % decrease					
- a. Total tonnage: - About the same	x				x
- b. Pavement millings: - % increase					
- b. Pavement millings: - % decrease					
- b. Pavement millings: - About the same	x				x
- c. Full depth pavement removal: - % increase					
- c. Full depth pavement removal: - % decrease					
- c. Full depth pavement removal: - About the same					x
- d. Others: - Text					
- d. Others: - % increase					
- d. Others: - % decrease					
- d. Others: - About the same					x
Reason for the change in the previous question, if any? - Selected Choice		No change	No change		No change
Reason for the change in the previous question, if any? - Pavement millings: - Text					
Reason for the change in the previous question, if any? - Full depth pavement removal: - Text					
Reason for the change in the previous question, if any? - Other: - Text					

Completed surveys

Question	Response #1	Response #2	Response #3	Response #4	Response #5
Agency type	County	County	Township	County	County
Agency:	Tuscarawas County	Stark County Engineer's Office	Rutland Township	fayette county	Defiance County
Name:	Joe Bachman	Jason Manson	Opal Dyer	Steve Luebbe	Warren Schlatter
Position:	County Engineer	Assistant Highway Engineer	Fiscal Officer	engineer	County Engineer
Phone Number:	3303396648	330-477-6781	740-742-2805	7403351541	419-782-4751
Email Address:	tcejoe@yahoo.com	jpmanson@starkcountyohio.gov	o_dyer@yahoo.com	steve.luebbe@fayette-co-oh.com	dce@defiance-county.com
Approximately how much RAP (tons) was used in each application in 2019?					
- HMA: - Amount (tons)					
- Granular base: - Amount (tons)					
- Fill: - Amount (tons)					
- Shoulder/berm: - Amount (tons)	1500	100			
- Cold central plant recycle mix: - Amount (tons)					
- Chip Seal Aggregate: - Amount (tons)					
- Aggregate Road Surfacing: - Amount (tons)					
- Stockpiled for the next year: - Amount (tons)					
- Other: - Text					
- Other: - Amount (tons)					
What is the primary application for RAP pavement millings?	stabilized berm	berm			driveway or berm aggregate
Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?	Sometimes	Yes			Yes
How is RAP processed for each application?					
- HMA:					
- Granular base:					
- Fill:					
- Shoulder/berm:	No processing	No processing			
- Cold central plant recycle mix:					
- Chip Seal Aggregate:					
- Aggregate Road Surfacing:					
- Other:					
- Other: - Text					
If RAP is fractionated, what are the sizes of fractionation?					
If RAP is fractionated, who performs the fractionation?					
What is the estimated cost of processing RAP for each application used in your jurisdiction?					
- a. HMA: - Cost ($/ton)					
- b. Granular base: - Cost ($/ton)					
- c. Fill: - Cost ($/ton)					
- d. Shoulder/berm: - Cost ($/ton)	n/a				
- e. Cold central plant recycle mix: - Cost ($/ton)					
- f. Chip Seal Aggregate: - Cost ($/ton)					
- g. Aggregate Road Surfacing: - Cost ($/ton)					
- e. Other: - Text					
- e. Other: - Cost ($/ton)					

Completed surveys

Question	Response #1	Response #2	Response #3	Response #4	Response #5
Agency type	County	County	Township	County	County
Agency:	Tuscarawas County	Stark County Engineer's Office	Rutland Township	fayette county	Defiance County
Name:	Joe Bachman	Jason Manson	Opal Dyer	Steve Luebbe	Warren Schlatter
Position:	County Engineer	Assistant Highway Engineer	Fiscal Officer	engineer	County Engineer
Phone Number:	3303396648	330-477-6781	740-742-2805	7403351541	419-782-4751
Email Address:	tcejoe@yahoo.com	jpmanson@starkcountyohio.gov	o_dyer@yahoo.com	steve.luebbe@fayette-co-oh.com	dce@defiance-county.com
How long is RAP typically stored?	0 - 6 months	7 - 12 months			
What percentage of RAP is wasted and how is it disposed?	none				
What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?					
Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?	No	No			No
Which tests are conducted on your RAP stockpiles? Select all that apply.					
What is the approximate cost of storing RAP each year ($/ton/year)?	$1/ton/yr				

Question	Response #6	Response #7	Response #8	Response #14	Response #16
Agency type	Township	Township	County	County	County
Agency:	Gasper Township trustees	Windsor Township	Williams County Engineer	Medina County	Lorain County Engineer's Office
Name:	eric white	Robert Slusher	Steven Humphrey	Andy Conrad	Shaun Duffala
Position:	trustee (25 years)	Trustee	Highway Maintenance	County Engineer	Engineer IV
Phone Number:	9375339600	4402725795	419-636-2454	3307239559	440-329-5586
Email Address:	ewlibertarian@yahoo.com	windsortwp04@yahoo.com	stevenhumphrey@wmscoengineer.com	aconrad@medinaco.org	sduffala@loraincounty.us
Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?	none	Yes	15 mile	40,000	45000
Have you ever purchased RAP?	Yes	Yes	No	No	No
What was the average cost of RAP in $/ton?	pavement made with recycled material added to larger rock for basecoat $95.00	25.00/ton	?		n/a
About how much RAP did your jurisdiction stockpile in 2019?	We do not stockpile RAP	We do not stockpile RAP	We do not stockpile RAP	> 1500 tons	500 - 1,000 tons
For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?					
- Pavement millings	0	100	0	0	0
- Full depth pavement removal	0	0	0	0	0
- Other:	0	0	0	0	0
- Other: - Text					
How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change					
- a. Total tonnage: - % increase					
- a. Total tonnage: - % decrease				100	
- a. Total tonnage: - About the Same		X			
- b. Pavement millings: - % increase					
- b. Pavement millings: - % decrease				100	
. - b. Pavement millings: - About the Same		X			
- c. Full depth pavement removal: - % increase					
- c. Full depth pavement removal: - % decrease					
- c. Full depth pavement removal: - About the Same				x	
- d. Other: - Text	no paving in 10				
- d. Other: - % increase					
- d. Other: - % decrease					
- d. Other: - About the Same				x	

Question	Response #6	Response #7	Response #8	Response #14	Response #16
Agency type	Township	Township	County	County	County
Agency:	Gasper Township trustees	Windsor Township	Williams County Engineer	Medina County	Lorain County Engineer's Office
Name:	eric white	Robert Slusher	Steven Humphrey	Andy Conrad	Shaun Duffala
Position:	trustee (25 years)	Trustee	Highway Maintenance	County Engineer	Engineer IV
Phone Number:	9375339600	4402725795	419-636-2454	3307239559	440-329-5586
Email Address:	ewlibertarian@yahoo.com	windsortwp04@yahoo.com	stevenhumphrey@wmscoengineer.com	aconrad@medinaco.org	sduffala@loraincounty.us
Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.					
- a. Total tonnage: - % increase					
- a. Total tonnage: - % decrease		100			
- a. Total tonnage: - About the same					
- b. Pavement millings: - % increase					
- b. Pavement millings: - % decrease		100			
- b. Pavement millings: - About the same					
- c. Full depth pavement removal: - % increase					
- c. Full depth pavement removal: - % decrease					
- c. Full depth pavement removal: - About the same					
- d. Others: - Text	chip seal patch only				
- d. Others: - % increase					
- d. Others: - % decrease					
- d. Others: - About the same					
Reason for the change in the previous question, if any? - Selected Choice	Other:	Pavement millings:	No change,Full depth pavement removal:	Pavement millings:	Pavement millings:
Reason for the change in the previous question, if any? - Pavement millings: - Text		We used pavement millings in our dust control - we didn't like the result		We have a stockpile from previous years and did not stockpile any material 2019. We will bring more material in as the pile is used.	We don't purchase it, we just pile up what we can based on how much milling is done. Some years we do not even take it from our resurfacing projects if our stockpile is big enough. Hard to judge tonnage that way, so I apologize for not answering some of the questions.
Reason for the change in the previous question, if any? - Full depth pavement removal: - Text			0		
Reason for the change in the previous question, if any? - Other: - Text	I love the grindings for berm material				

Question	Response #6	Response #7	Response #8	Response #14	Response #16
Agency type	Township	Township	County	County	County
Agency:	Gasper Township trustees	Windsor Township	Williams County Engineer	Medina County	Lorain County Engineer's Office
Name:	eric white	Robert Slusher	Steven Humphrey	Andy Conrad	Shaun Duffala
Position:	trustee (25 years)	Trustee	Highway Maintenance	County Engineer	Engineer IV
Phone Number:	9375339600	4402725795	419-636-2454	3307239559	440-329-5586
Email Address:	ewlibertarian@yahoo.com	windsortwp04@yahoo.com	stevenhumphrey@wmscoengineer.com	aconrad@medinaco.org	sduffala@loraincounty.us
Approximately how much RAP (tons) was used in each application in 2019?					
- HMA: - Amount (tons)				5000	
- Granular base: - Amount (tons)					
- Fill: - Amount (tons)					
- Shoulder/berm: - Amount (tons)				200	
- Cold central plant recycle mix: - Amount (tons)					
- Chip Seal Aggregate: - Amount (tons)					
- Aggregate Road Surfacing: - Amount (tons)		500			
- Stockpiled for the next year: - Amount (tons)		0			
- Other: - Text	wrong guy, eieio zip code				As needed
- Other: - Amount (tons)					
What is the primary application for RAP pavement millings?		dust control		intermediate asphalt course	drives / berm / parking lot at County Garage
Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?		Yes	No	Yes	No
How is RAP processed for each application?					
- HMA:					
- Granular base:					
- Fill:					
- Shoulder/berm:					
- Cold central plant recycle mix:					
- Chip Seal Aggregate:					
- Aggregate Road Surfacing:		Crushing/grinding AND Screening/fractionation			
- Other:					
- Other: - Text					
If RAP is fractionated, what are the sizes of fractionation?		About the size of #8 limestone			
If RAP is fractionated, who performs the fractionation?	Barret Marerials	Arms Trucking			
What is the estimated cost of processing RAP for each application used in your jurisdiction?					
- a. HMA: - Cost ($/ton)					
- b. Granular base: - Cost ($/ton)					
- c. Fill: - Cost ($/ton)					
- d. Shoulder/berm: - Cost ($/ton)					
- e. Cold central plant recycle mix: - Cost ($/ton)					
- f. Chip Seal Aggregate: - Cost ($/ton)		25.00			
- g. Aggregate Road Surfacing: - Cost ($/ton)					
- e. Other: - Text	base coat w top chip/seal				
- e. Other: - Cost ($/ton)					

Question	Response #6	Response #7	Response #8	Response #14	Response #16
Agency type	Township	Township	County	County	County
Agency:	Gasper Township trustees	Windsor Township	Williams County Engineer	Medina County	Lorain County Engineer's Office
Name:	eric white	Robert Slusher	Steven Humphrey	Andy Conrad	Shaun Duffala
Position:	trustee (25 years)	Trustee	Highway Maintenance	County Engineer	Engineer IV
Phone Number:	9375339600	4402725795	419-636-2454	3307239559	440-329-5586
Email Address:	ewlibertarian@yahoo.com	windsortwp04@yahoo.com	stevenhumphrey@wmscoengineer.com	aconrad@medinaco.org	sduffala@loraincounty.us
How long is RAP typically stored?		0 - 6 months			1 - 3 years
What percentage of RAP is wasted and how is it disposed?	none, berm with all we can get	0%			We don't dispose of any in our yard. We may elect not to take any though from our resurfacings
What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?					Sometimes we choose to not take millings from a road which has a lot of cold patch repair in it.
Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?	No	No			No
Which tests are conducted on your RAP stockpiles? Select all that apply.					
What is the approximate cost of storing RAP each year ($/ton/year)?		$0			Cost would be included in our daily operations. Cannot attribute a cost specifically for that

Question	Response #17	Response #18	Response #19	Response #20
Agency type	County	County	County	County
Agency:	Ashland County Engineer	Wayne County	Crawford County	Huron County
Name:	Edward J Meixner	Ryan P. Marthey, P.E.	Jason Long	
Position:	County Engineer	Highway & Drainage Engineer	Administrator	
Phone Number:	419-282-4281	330-621-1263	419-562-7731	
Email Address:	emeixner@ashlandcounty.org	rpm@wayne-county-engineer.com	jasonl@crawford-co.org	
Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?	Minimal. Usually only at intersections and bridge approaches.	25k	0-60,000	0-10,000
Have you ever purchased RAP?	No	No	Yes	No
What was the average cost of RAP in $/ton?	N.A.	$6.00	$5.00	
About how much RAP did your jurisdiction stockpile in 2019?	< 500 tons	> 1,500 tons	500 - 1,000 tons	500 - 1,000 tons
For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?				
- Pavement millings	100		50	100
- Full depth pavement removal	0		50	0
- Other:	0			
- Other: - Text				
How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change				
- a. Total tonnage: - % increase				
- a. Total tonnage: - % decrease			50	
- a. Total tonnage: - About the Same				X
- b. Pavement millings: - % increase				
- b. Pavement millings: - % decrease			50	
.- b. Pavement millings: - About the Same				X
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the Same				
- d. Other: - Text				
- d. Other: - % increase				
- d. Other: - % decrease				
- d. Other: - About the Same				

Question	Response #17	Response #18	Response #19	Response #20
Agency type	County	County	County	County
Agency:	Ashland County Engineer	Wayne County	Crawford County	Huron County
Name:	Edward J Meixner	Ryan P. Marthey, P.E.	Jason Long	
Position:	County Engineer	Highway & Drainage Engineer	Administrator	
Phone Number:	419-282-4281	330-621-1263	419-562-7731	
Email Address:	emeixner@ashlandcounty.org	rpm@wayne-county-engineer.com	jasonl@crawford-co.org	
Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.				
- a. Total tonnage: - % increase			75	
- a. Total tonnage: - % decrease				
- a. Total tonnage: - About the same				X
- b. Pavement millings: - % increase			75	
- b. Pavement millings: - % decrease				
- b. Pavement millings: - About the same				X
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the same			X	
- d. Others: - Text				
- d. Others: - % increase				
- d. Others: - % decrease				
- d. Others: - About the same				
Reason for the change in the previous question, if any? - Selected Choice			Pavement Millings	No change
Reason for the change in the previous question, if any? - Pavement millings: - Text			Milling an entire road for paving, we do not typically mill our roads	
Reason for the change in the previous question, if any? - Full depth pavement removal: - Text				
Reason for the change in the previous question, if any? - Other: - Text				

Question	Response #17	Response #18	Response #19	Response #20
Agency type	County	County	County	County
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Position:	County Engineer	Highway & Drainage Engineer	Administrator	
Phone Number:	419-282-4281	330-621-1263	419-562-7731	
Email Address:	emeixner@ashlandcounty.org	rpm@wayne-county-engineer.com	jasonl@crawford-co.org	
Approximately how much RAP (tons) was used in each application in 2019?				
- HMA: - Amount (tons)				
- Granular base: - Amount (tons)				
- Fill: - Amount (tons)				100
- Shoulder/berm: - Amount (tons)			1500	
- Cold central plant recycle mix: - Amount (tons)				
- Chip Seal Aggregate: - Amount (tons)				
- Aggregate Road Surfacing: - Amount (tons)				
- Stockpiled for the next year: - Amount (tons)			1500	
- Other: - Text			residential drive approaches	driveways
- Other: - Amount (tons)			500	200
What is the primary application for RAP pavement millings?			road edge berm	Driveways
Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?			Yes	No
How is RAP processed for each application?				
- HMA:				
- Granular base:				
- Fill:				No processing
- Shoulder/berm:			Crushing/grinding AND Screening/fractionation	
- Cold central plant recycle mix:				
- Chip Seal Aggregate:				
- Aggregate Road Surfacing:				
- Other:				No processing
- Other: - Text				Driveways
If RAP is fractionated, what are the sizes of fractionation?			3/8-3/4	
If RAP is fractionated, who performs the fractionation?			rent a crusher/processor	
What is the estimated cost of processing RAP for each application used in your jurisdiction?				
- a. HMA: - Cost ($/ton)				
- b. Granular base: - Cost ($/ton)				
- c. Fill: - Cost ($/ton)				
- d. Shoulder/berm: - Cost ($/ton)			$2.00	
- e. Cold central plant recycle mix: - Cost ($/ton)				
- f. Chip Seal Aggregate: - Cost ($/ton)				
- g. Aggregate Road Surfacing: - Cost ($/ton)				
- e. Other: - Text				
- e. Other: - Cost ($/ton)				

Question	Response #17	Response #18	Response #19	Response #20
Agency type	County	County	County	County
Agency:	Ashland County Engineer	Wayne County	Crawford County	Huron County
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Position:	County Engineer	Highway & Drainage Engineer	Administrator	
Phone Number:	419-282-4281	330-621-1263	419-562-7731	
Email Address:	emeixner@ashlandcounty.org	rpm@wayne-county-engineer.com	jasonl@crawford-co.org	
How long is RAP typically stored?			1 - 3 years	1 - 3 years
What percentage of RAP is wasted and how is it disposed?			0	
What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?				
Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?			No	No
Which tests are conducted on your RAP stockpiles? Select all that apply.				
What is the approximate cost of storing RAP each year ($/ton/year)?			0	?

Question	Response #11	Response #12	Response #13	Response #15
Agency type	County	Township	Township	City
Agency:	Fulton County Engineers Office	Tuscarawas Township Stark County	marion twp	City of Monroe Ohio
Name:	Mike Burkholder	Denny Britton	todd cremean	John bodiker
Position:	Civil Technition	Road Foreman	road worker	Eng Tech - Inspector
Phone Number:	419-335-1715	330-832-4337	7403850435	5137278953
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	mariontwp37@yahoo.com	bodikerj@monroeohio.org
Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?	three to four miles per year	0	none	7400
Have you ever purchased RAP?	No	No	Yes	No
What was the average cost of RAP in $/ton?		20.00	15	unknown
About how much RAP did your jurisdiction stockpile in 2019?	1,000 - 1,500 tons		< 500 tons	We do not stockpile RAP
For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?				
- Pavement millings	0	0	100	0
- Full depth pavement removal	0	0	0	0
- Other:	0	0	0	0
- Other: - Text	2"			
How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change				
- a. Total tonnage: - % increase				
- a. Total tonnage: - % decrease				
- a. Total tonnage: - About the Same			x	x
- b. Pavement millings: - % increase				
- b. Pavement millings: - % decrease				
. - b. Pavement millings: - About the Same			x	x
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the Same				x
- d. Other: - Text				
- d. Other: - % increase				
- d. Other: - % decrease				
- d. Other: - About the Same				x

Question	Response #11	Response #12	Response #13	Response #15
Agency type	County	Township	Township	City
Agency:	Fulton County Engineers Office	Tuscarawas Township Stark County	marion twp	City of Monroe Ohio
Name:	Mike Burkholder	Denny Britton	todd cremean	John bodiker
Position:	Civil Technition	Road Foreman	road worker	Eng Tech - Inspector
Phone Number:	419-335-1715	330-832-4337	7403850435	5137278953
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	mariontwp37@yahoo.com	bodikerj@monroeohio.org
Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.				
- a. Total tonnage: - % increase				
- a. Total tonnage: - % decrease				
- a. Total tonnage: - About the same			x	x
- b. Pavement millings: - % increase				
- b. Pavement millings: - % decrease				
- b. Pavement millings: - About the same			x	x
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the same				x
- d. Others: - Text				
- d. Others: - % increase				
- d. Others: - % decrease				
- d. Others: - About the same				x
Reason for the change in the previous question, if any? - Selected Choice	No change		No change	Pavement millings:
Reason for the change in the previous question, if any? - Pavement millings: - Text				we ask for everything to be returned to the plant and recycled... we currently allow up to 8%
Reason for the change in the previous question, if any? - Full depth pavement removal: - Text				
Reason for the change in the previous question, if any? - Other: - Text				

Question	Response #11	Response #12	Response #13	Response #15
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Name:	Mike Burkholder	Denny Britton	todd cremean	John bodiker
Position:	Civil Technition	Road Foreman	road worker	Eng Tech - Inspector
Phone Number:	419-335-1715	330-832-4337	7403850435	5137278953
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	mariontwp37@yahoo.com	bodikerj@monroeohio.org
Approximately how much RAP (tons) was used in each application in 2019?				
- HMA: - Amount (tons)				
- Granular base: - Amount (tons)			20	
- Fill: - Amount (tons)				
- Shoulder/berm: - Amount (tons)			60	
- Cold central plant recycle mix: - Amount (tons)				
- Chip Seal Aggregate: - Amount (tons)				
- Aggregate Road Surfacing: - Amount (tons)			20	
- Stockpiled for the next year: - Amount (tons)				
- Other: - Text				
- Other: - Amount (tons)				
What is the primary application for RAP pavement millings?			berming	
Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?	No		Yes	
How is RAP processed for each application?				
- HMA:				
- Granular base:				
- Fill:				
- Shoulder/berm:	Crushing/grinding			
- Cold central plant recycle mix:				
- Chip Seal Aggregate:				
- Aggregate Road Surfacing:				
- Other:				
- Other: - Text				
If RAP is fractionated, what are the sizes of fractionation?	1/8			
If RAP is fractionated, who performs the fractionation?	contractor			
What is the estimated cost of processing RAP for each application used in your jurisdiction?				
- a. HMA: - Cost ($/ton)				
- b. Granular base: - Cost ($/ton)				
- c. Fill: - Cost ($/ton)				
- d. Shoulder/berm: - Cost ($/ton)				
- e. Cold central plant recycle mix: - Cost ($/ton)				
- f. Chip Seal Aggregate: - Cost ($/ton)				
- g. Aggregate Road Surfacing: - Cost ($/ton)				
- e. Other: - Text				
- e. Other: - Cost ($/ton)				

Question	Response #11	Response #12	Response #13	Response #15
Agency type	County	Township	Township	City
Agency:	Fulton County Engineers Office	Tuscarawas Township Stark County	marion twp	City of Monroe Ohio
Name:	Mike Burkholder	Denny Britton	todd cremean	John bodiker
Position:	Civil Technition	Road Foreman	road worker	Eng Tech - Inspector
Phone Number:	419-335-1715	330-832-4337	7403850435	5137278953
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	mariontwp37@yahoo.com	bodikerj@monroeohio.org
How long is RAP typically stored?	7 - 12 months			
What percentage of RAP is wasted and how is it disposed?	10, berm			
What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?	gradation			
Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?	No			
Which tests are conducted on your RAP stockpiles? Select all that apply.				
What is the approximate cost of storing RAP each year ($/ton/year)?	0			

Question	Phone Interview #1	Phone Interview #2 (email)	Phone Interview #3	Phone Interview #4
Agency type	County	County	County	City
Agency:	Washington County	Auglaize County	Butler County	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Gerg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent
Phone Number:	740-376-7430	419-739-6520	513-785-4143	740-687-6668
Email Address:	rwright@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org	
Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?	not normally done (mostly overlay)	Of 3000 tons of RAP acquired in 2019, 20% from reconstruction and milling)	35,911 SY at 1.5" deep in 2020	
Have you ever purchased RAP?	Yes, have purchased waste material. Would like to purchase but hard to come by	No	No	No, don't purchase it, retain what the need from pavement millings
What was the average cost of RAP in $/ton?	$10-12/ton (waste product from producer)			
About how much RAP did your jurisdiction stockpile in 2019?	0	3000 tons acquired in 2019. Not uncommon to carry 500 - 600 tons to the next year	0. They do not use RAP (paved shoulders so need for berm)	Currently have 7000 tons stockpiled (cumulative from the last couple years) for a RAP chip seal and/or RAP microsurfacing they have been wanting to try with Asphalt Materials
For each category of RAP, approximately what percent of the total tonnage was acquired in 2019?				
- Pavement millings		20% (county projects, reconstruction and milling)		
- Full depth pavement removal		40% (from contractors, mostly driveway and parking lot replacement)		
- Other:		40% (county projects, road repairs, storm sewer crossings, etc.)		
- Other: - Text				
How does the amount of RAP acquired in 2019 compare with previous years? Please provide approximate percent change in the appropriate column or type "X" in the last column if there was little to no change				
- a. Total tonnage: - % increase				
- a. Total tonnage: - % decrease				All RAP acquired in 2020 was sent to Parks Service for their parking lots. Did not save any for roadway repair.
- a. Total tonnage: - About the Same		About the same		
- b. Pavement millings: - % increase				
- b. Pavement millings: - % decrease				
. - b. Pavement millings: - About the Same		about the same		
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the Same				
- d. Other: - Text				
- d. Other: - % increase				
- d. Other: - % decrease				
- d. Other: - About the Same				

Question	Phone Interview #1	Phone Interview #2 (email)	Phone Interview #3	Phone Interview #4
Agency type	County	County	County	City
Agency:	Washington County	Auglaize County	Butler County	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Greg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent
Phone Number:	740-376-7430	419-739-6520	513-785-4143	740-687-6668
Email Address:	rwright@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org	
Do you expect the amounts to increase or decrease in 2020? Please provide approximate percent change in the appropriate column or type "X" in the last column if little to no change is expected.				
- a. Total tonnage: - % increase				
- a. Total tonnage: - % decrease				
- a. Total tonnage: - About the same				
- b. Pavement millings: - % increase				
- b. Pavement millings: - % decrease				
- b. Pavement millings: - About the same				
- c. Full depth pavement removal: - % increase				
- c. Full depth pavement removal: - % decrease				
- c. Full depth pavement removal: - About the same				
- d. Others: - Text				
- d. Others: - % increase				
- d. Others: - % decrease				
- d. Others: - About the same				
Reason for the change in the previous question, if any? - Selected Choice				
Reason for the change in the previous question, if any? - Pavement millings: - Text				Amount retained from milling depends on their need that year
Reason for the change in the previous question, if any? - Full depth pavement removal: - Text				
Reason for the change in the previous question, if any? - Other: - Text				

Question	Phone Interview #1	Phone Interview #2 (email)	Phone Interview #3	Phone Interview #4
Agency type	County	County	County	City
Agency:	Washington County	Auglaize County	Butler County	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Greg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent
Phone Number:	740-376-7430	419-739-6520	513-785-4143	740-687-6668
Email Address:	rwright@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org	
Approximately how much RAP (tons) was used in each application in 2019?				
- HMA: - Amount (tons)				150 -160 tons of RAP used with portable plant (produced 1.5 tons of HMA at a time) for pothole repairs
- Granular base: - Amount (tons)				Amount not provided but indicated RAP was being used by Parks Service for base in parking lots
- Fill: - Amount (tons)				
- Shoulder/berm: - Amount (tons)	1			Amount not provided but indicated RAP is used for berm, drives and a little bit of everything
- Cold central plant recycle mix: - Amount (tons)				Have not done it yet, but hopes to in the future
- Chip Seal Aggregate: - Amount (tons)				Have not done it yet, but it is in the works
- Aggregate Road Surfacing: - Amount (tons)				
- Stockpiled for the next year: - Amount (tons)				
- Other: - Text				
- Other: - Amount (tons)				
What is the primary application for RAP pavement millings?	berm	Did not indicate if millings only; RAP used to repair roadway cuts for storm sewers and pavement widening projects		Pothole repair (portable HMA plant), berm, drives, stockpiling it for chip seal and microsurfacing
Are pavement millings kept in a stockpile separate from other types of RAP (e.g. full depth removal)?				
How is RAP processed for each application?				
- HMA:				did not indicate it was processed
- Granular base:				
- Fill:				
- Shoulder/berm:				
- Cold central plant recycle mix:				
- Chip Seal Aggregate:				will have Asphalt materials process to #8s for chip seal and process for micro-surfacing
- Aggregate Road Surfacing:				
- Other:				
- Other: - Text				
If RAP is fractionated, what are the sizes of fractionation?				
If RAP is fractionated, who performs the fractionation?				
What is the estimated cost of processing RAP for each application used in your jurisdiction?				
- a. HMA: - Cost ($/ton)				
- b. Granular base: - Cost ($/ton)				
- c. Fill: - Cost ($/ton)				
- d. Shoulder/berm: - Cost ($/ton)				
- e. Cold central plant recycle mix: - Cost ($/ton)				
- f. Chip Seal Aggregate: - Cost ($/ton)				did not know cost, processing plant belongs to Asphalt
- g. Aggregate Road Surfacing: - Cost ($/ton)				
- e. Other: - Text				
- e. Other: - Cost ($/ton)		$3/ton includes cost for grinding and stacking		

Question	Phone Interview #1	Phone Interview #2 (email)	Phone Interview #3	Phone Interview #4
Agency type	County	County	County	City
Agency:	Washington County	Auglaize County	Butler County	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Greg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent
Phone Number:	740-376-7430	419-739-6520	513-785-4143	740-687-6668
Email Address:	rwright@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org	
How long is RAP typically stored?				can't keep it too long, but sounds like they have some stored from 2014/2015
What percentage of RAP is wasted and how is it disposed?				
What are some reasons RAP is disposed of (e.g. gradation is too fine, too much dust, etc.) ?				
Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.) ?				not right now, but plan to for chip seal and microsurfacing
Which tests are conducted on your RAP stockpiles? Select all that apply.				
What is the approximate cost of storing RAP each year ($/ton/year)?				

13.3 Phone Interviews with Selected Counties

13.3.1 Phone Interviews, Questions

City/County: ______________________
Name: _______________________
Position: _____________________
Phone Number: _______________
Email address: ________________

1. Have you ever purchased RAP for your jurisdiction, if so, what was the approximate cost?
    a. _____________________________
2. For what application did you purchase RAP?
    a. ___HMA
    b. ___Granular base
    c. ___Fill
    d. ___Shoulder/Berm material
    e. ___Aggregate Road surfacing
    f. ___Chip seal aggregate
    g. ___Other: ____________
3. Approximately how much pavement planing (milling) (in SY) is conducted each year as part of your paving projects?
4. What percentage (or tonnage) of those pavement millings are retained by the county?
    a. ____________________________
5. Is any of the pavement millings stockpiled? If so, approximately how much?
    a. ____________________________
6. For what applications are the millings used?
    a. ___HMA
    b. ___Granular base
    c. ___Fill
    d. ___Shoulder/Berm material
    e. ___Aggregate Road surfacing
    f. ___Chip seal aggregate
    g. ___Other: ____________
7. Does your county maintain a stockpile of RAP?
    a. ___Yes
    b. ___No
8. Approximately how much RAP was stockpiled last year (2019)?
    a. ___________________________________
9. Of the RAP stockpiled, what percentage came from
    a. ___Pavement millings
    b. ___Full depth pavement removal
    c. ___Other: ____________
10. How does the amount of RAP stockpiled compare to years past? Please provide approximate percent change:
    a. ___ % increase
    b. ___ % decrease
    c. ___ about the same

11. Do you expect the amount to increase or decrease in 2020?
    a. ___ increase
    b. ___ decrease
    c. ___ about the same
12. Approximately what percentage of the RAP stockpiled by the county is used in each application?
    a. ___% or tonnage HMA
    b. ___% or tonnage Granular base
    c. ___% or tonnage Fill
    d. ___% or tonnage Shoulder/berm
    e. ___% or tonnage Cold central plant recycle mix
    f. ___% or tonnage Chip Seal Aggregate
    g. ___% or tonnage Aggregate Road Surfacing
    h. ___% or tonnage stockpiled for the next year
    i. ___% or tonnage Other:_____________________________________
13. How is RAP processed for each application?
    a. RAP is not processed, go to question 16
    b. HMA: ______________
    c. Granular base: __________
    d. Fill: ______________
    e. Shoulder/berm: ___________
    f. Cold central plant recycle mix: ___________
    g. Chip Seal Aggregate: _____________
    h. Aggregate Road Surfacing: _____________
    i. Other:_____________________________________
14. If RAP is fractionated,
    c. What are the sizes of fractionation?
    d. Who performs the fractionation?
15. Estimated cost of processing RAP for each application?
    a. RAP is not processed
    b. HMA
    c. Granular base
    d. Fill
    e. Shoulder/berm
    f. Cold central plant recycle mix
    g. Chip Seal Aggregate
    h. Aggregate Road Surfacing
    i. Other:_____________________________________
16. How long is RAP typically stored?
    a. _____________________
17. Is any testing conducted on RAP stockpiles (e.g. gradation, moisture, etc.)? If so, can we obtain a copy of the results?
    a. ___Yes
    b. ___No
18. What is the approximate cost of storing RAP each year ($/ton/year)?
    a. ________$/ton/year

Pavement Preservation Treatments

1. Have chip seals, microsurfacing, or slurry seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?
    a. ___ Yes, chip seals have been placed
    b. ___ Yes, micro-surfacing has been placed
    c. ___ Yes, slurry seals have been placed
    d. ___ Yes, both, chip seals and microsurfacing, have been placed
    e. ___Yes, both, chip seals and slurry seals, have been placed
    f. ___Yes, both, microsurfacing and slurry seals have been placed
    g. ___ No, you have completed the questionnaire, thank you.
2. For each applicable treatment, approximately how much was placed in your county in 2019?
    a. Chip seals: ______________________
    b. Slurry seals: _____________________
    c. Microsurfacing: ___________________
    d. Otta seals: ______________________
3. Is this an increase or decrease from previous years?
    a. Chip seals: ______________________
    b. Slurry seals: _____________________
    c. Microsurfacing: ___________________
    d. Otta seals: ______________________
4. For each applicable treatment, what aggregate and emulsion (or asphalt binder) are used?
    a. Chip seals:
        i. Aggregate type: _________________
        ii. Aggregate size: _________________
        iii. Emulsion/binder: _______________
    b. Slurry seals:
        i. Aggregate type: _________________
        ii. Aggregate size: _________________
        iii. Emulsion/binder: _______________
    c. Microsurfacing:
        i. Aggregate type: _________________
        ii. Aggregate size: _________________
        iii. Emulsion/binder: _______________
    d. Otta seals:
        i. Aggregate type: _________________
        ii. Aggregate size: _________________
        iii. Emulsion/binder: _______________
5. What is the typical aggregate rate (lbs/SY) used for each applicable treatment?
    a. Chip seals:
        i. Rate (lbs/SY): ________
    b. Slurry seals:
        i. Rate (lbs/SY): ________
    c. Microsurfacing:
        i. Rate (lbs/SY): ________
    d. Otta seals:
        i. Rate (lbs/SY): ________

6. What is the average cost of aggregate ($/SY or $/ton) for each applicable treatment? If not by priced separately, what is the average cots for the treatment?
    a. Chip seals: ______________________
    b. Slurry seals: _____________________
    c. Microsurfacing: __________________
    d. Otta seals: ______________________

14 Appendix C: Assessment of Demand in Ohio

14.1 Survey of Local Agencies, Summary

A survey was sent to local agencies through Ohio's LTAP email distribution list. Additionally, phone interviews were conducted as described in Appendix B, section 13.2, and with questions listed in Section 4.3, in which participants were asked to report information related to the amount of chip seal, microsurfacing, slurry seals or Otta seals placed each year, as well as aggregate type, emulsion type, aggregate and emulsion application rates, and cost of the virgin aggregate used in each treatment. Responses to survey and the second half of the phone interview in which similar questions were asked are presented together in the following subsection.

A total of 17 agencies responded to the survey and phone interviews, with the majority representing counties (12), followed by townships (3) and cities (2). Two agencies, Butler County, and Windsor Township responded they do not place chip seal, microsurfacing, slurry seal, nor Otta seal and therefore are not included in any further analysis or summaries although their responses are tabulated in section 5.3. The survey and phone interviews found 15 local agencies were using chip seals, four of which were also using microsurfacing, two agencies reported none of the listed pavement preservation treatments were being used, and no agencies have placed Otta seals.

Regarding information pertaining to chip seal, 15 agencies indicated they had placed chip seal in the last 5 years. Agencies were then asked to report the amount of chip seal in either SY, lane-miles or tons of aggregate, placed in 2019. Only one agency, Wayne County indicated they did not place any chip seal in 2019. Results among the other 14 agencies varied widely. Agencies reported the amount of chip seal placed in 2019 in units of SY, "miles", lane-miles or tons of virgin aggregate. Where units of miles were provided, lane miles were assumed, and assuming 12-ft lanes, the amount in SY was estimated from the number of lane-miles. Where tons of virgin aggregate were supplied the provided aggregate application rate was used to estimate the amount of chip seal in SY. As such amounts varied greatly with values ranging from 21,120 SY to 844,800 SY, as shown in Figure 14-1.

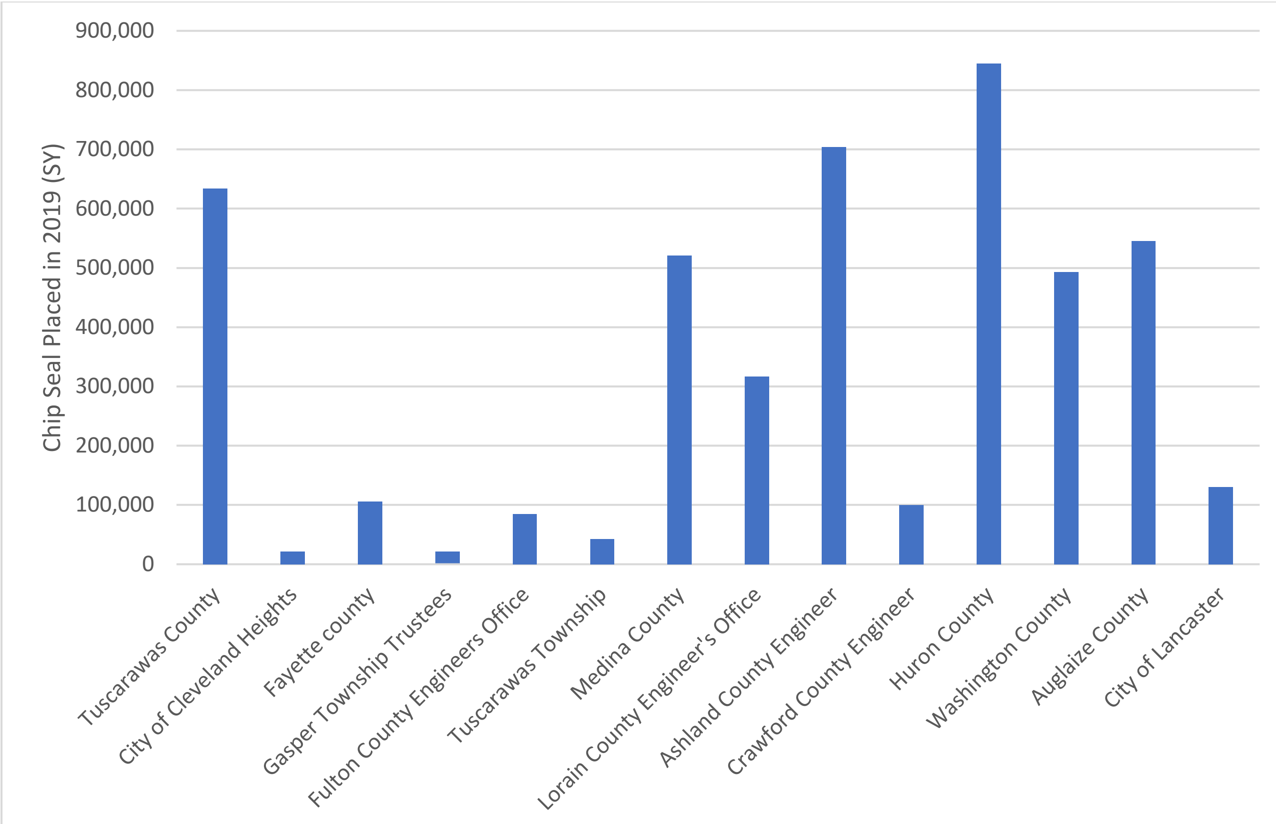

Figure 14-1 Amount of Chip Seal (SY) Placed in 2019, Survey and Phone Interview Results

Half of the 14 agencies which placed chip seal in 2019 indicated chip seals were placed by a contractor, while three respondents placed chip seals using in-house crews, and one agency uses either contractor or in-house crews to place chip seals. Three agencies did not provide a response. Ten respondents noted the amount of chip seals placed in 2019 is about the same as previous years, while two respondents noted a slight increase, and two noted a moderate decrease in the amount placed in 2019 relative to past years.

Agencies were asked to report the cost of the virgin aggregate used for chip seal. Some agencies indicated the cost was included in the total cost of the chip seal. One agency provided a total cost of chip seal of $1.20/SY in 2019. Another agency responded with $15,000/mile which is assumed to be for the total unit cost of chip seal; when 12-ft lanes are assumed, and the cost is assumed to be per lane-mile, this is equivalent to $1.07/SY. If 10-ft lanes are assumed, the cost increases to $1.28/SY. The cost for chip seal aggregate varied, as ten agencies provided unit costs ranging from $6/ton to $80/ton. One respondent was as low as $6/ton, three reported values in the $11-15/ton range, two reported values between $18/ton and $20/ton, and three reported values of $22/ton to $25/ton. It should be noted, one agency indicated they use either river gravel at $12/ton to $15/ton or limestone at $22/ton to $24.50/ton. Two respondents noted very high aggregate costs with one $35/ton and another at $80/ton. The research team assumes hauling costs may have contributed to a cost of $80/ton. One county provided detailed information for their chip seal program from 2013 to 2019.

Respondents were asked to report the aggregate type and size for the two main types of aggregate used for chip seal. Overall, the most common used was a No. 8 limestone. Other aggregate types reported included slag (as well as air cooled blast furnace slag), and gravel (as well as river gravel). A previous research study on chip seal for Ohio's local agencies has also shown crushed river gravel is also used for chip seal in Ohio (Green et al. 2018). Other aggregate sizes included No. 9 and No. 57, although 13 of the 14 responses indicated the primary aggregate was of a No. 8 size and 3 of the 5 responses for the secondary aggregate were also reported as No. 8.

Agencies reported aggregate application rates between 18 lb/SY and 25 lb/SY with higher frequencies (10 of 13 responses) falling between 22 lb/SY and 25 lb/SY. Of the other three responses, two were 20 lb/SY and one was 18-22 lb/SY.

Although four agencies indicated microsurfacing had been placed in their jurisdiction in the last 5 years, only one indicated any had been placed in the year 2019. The City of Lancaster provided an amount of 60,000 to 70,000 SY at a cost of $2.90/SY to $3.40/SY. They also indicated limestone aggregate was used in their microsurfacing.

14.2 Survey of Local Agencies, Questions

Project: "Design of Microsurfacing and Chip Seal Mixes with RAP for Local Roadway Application"

Sponsored by Ohio Research Initiative for Locals (ORIL)

Thank you for your willingness to participate in this survey. This survey is intended to identify the amount of chip seals, slurry seals, microsurfacing, and Otta seals placed on local roads across the state. Additionally, information regarding aggregate type, and costs for these preservation treatments is sought. We are asking only representatives of local agencies to respond to this survey. The researchers thank you for your time and contribution to this valuable research. If you have any questions or comments, you may contact the lead researcher, Mary Robbins, Ph.D., at robbinm1@ohio.edu

Participants Info

Agency:

Name:

Position:

Phone Number:

Email Address:

General

Have chip seals, microsurfacing, slurry seals or Otta seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?

Yes

No

This questionnaire has multiple sections. A back button is not available across the sections.

Please select all applicable treatments that have been placed in your jurisdiction in the past 5 years.

Chip Seals

Microsurfacing

Slurry Seals

Otta Seals

Chip Seals

Are chip seals placed by:

County/city crews

Contract

Both county/city crews and contract

Other:

In 2019, what was the approximate amount (SY or lane miles or tons) of chip seals placed in your jurisdiction?

In general, how does the amount of chip seals placed in 2019 compare to previous years?

moderate decrease

slight decrease

about the same

slight increase

moderate increase

What was the average cost ($/ton or $/CY) of chip seal aggregate in 2019?

How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference.

More ($/ton):

Less ($/ton):

About the same as previous years

What aggregate is utilized for chip seals and where is it sourced from?

	Aggregate 1	Aggregate 2
a. Aggregate Type (e.g. limestone, gravel, slag, etc.):		
b. Size (e.g. #8s, #9s, #57s, #67s, etc.):		
c. Source:		

What is the typical aggregate rate (lbs/SY) used for chip seals?

What type of asphalt emulsion or binder is used for chip seals?

Do you have written specifications for chip seals, if so, may we have a copy?

Yes

No

Please provide a copy of your specifications of chip seals here or through email at robbinm1@ohio.edu. Only one file can be uploaded through this survey, if you wish to share more than one file you can either upload a zip file of send them via email to Mary Robbins at the address listed above.

Microsurfacing

Is microsurfacing placed by:

County/city crews

Contract

Both county/city crews and contract

Other:

In 2019, what was the approximate amount (SY or lane miles or tons) of microsurfacing placed in your jurisdiction?

In general, how does the amount of microsurfacing placed in 2019 compare to previous years?

moderate decrease

slight decrease

about the same

slight increase

moderate increase

What was the average cost of microsurfacing in 2019? Please indicate in your answer whether cost is $/ton or $/SY.

How does the average cost of microsurfacing compare to previous years? If known, please provide the approximate cost difference. Please indicate in your answer whether cost is $/ton or $/SY.

More:

Less:

About the same as previous years

What aggregate is predominately utilized for microsurfacing and where is it sourced from?

	Aggregate 1	Aggregate 2
a. Aggregate Type (e.g. limestone, gravel, slag, etc.)		
b. Size (e.g. ODOT a, ODOT b, ISSA Type I, ISSA Type II, ISSA Type II, etc.):		
c. Source:		

What is the typical application rate (lbs/SY) used for microsurfacing, if known?

What type of asphalt emulsion is used for microsurfacing?

Do you have written specifications for microsurfacing, if so, may we have a copy?

Yes

No

Please provide a copy of your specifications of microsurfacing here or through email at robbinm1@ohio.edu. Only one file can be uploaded through this survey, if you wish to share more than one file you can either upload a zip file of send them via email to Mary Robbins at the address listed above.

Slurry Seals

Are slurry seals placed by:

County/city crews

Contract

Both county/city crews and contract

Other:

In 2019, what was the approximate amount (SY or lane miles or tons) of slurry seals placed in your jurisdiction?

In general, how does the amount of slurry seals placed in 2019 compare to previous years?

moderate decrease

slight decrease

about the same

slight increase

moderate increase

What was the average cost of slurry seals in 2019? Please indicate in your answer whether cost is $/ton or $/SY.

How does the average cost of slurry seals compare to previous years? If known, please provide the approximate cost difference. Please indicate in your answer whether cost is $/ton or $/SY.

More:

Less:

About the same as previous years

What aggregate is predominately utilized for slurry seals and where is it sourced from?

	Aggregate 1	Aggregate 2
a. Aggregate Type (e.g. limestone, gravel, slag, etc.):		
b. Size (e.g. ISSA Type I, ISSA Type II, ISSA Type III, etc.):		
c. Source:		

What is the typical application rate (lbs/SY) used for slurry seals, if known?

What type of asphalt emulsion is used for slurry seals?

Do you have written specifications for slurry seals, if so, may we have a copy?

Yes

No

Please provide a copy of your specifications of slurry seals here or through email at robbinm1@ohio.edu. Only one file can be uploaded through this survey, if you wish to share more than one file you can either upload a zip file of send them via email to Mary Robbins at the address listed above.

Otta Seals

Are Otta seals placed by:

County/city crews

Contract

Both county/city crews and contract

Other:

Was any Otta seal placed in 2019?

Yes

No

What was the approximate quantity placed in 2019?

When was the last Otta seal placed in your jurisdiction? And about how much (SY or lane-miles or tons) was placed?

Year of placement:

Amount of Otta seal placed:

In terms of the amount of Otta seal placed in your jurisdiction, has the trend generally been increasing or decreasing over the last 5 years?

- moderate decrease
- slight decrease
- about the same
- slight increase
- moderate increase

What was the average cost ($/ton or $/CY) of Otta seal aggregate in 2019?

How does the average cost of Otta seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference.

More ($/ton):

Less ($/ton):

About the same as previous years

What aggregate is utilized for Otta seals and where is it sourced from?

Please provide the gradation for aggregate utilized for Otta seals.

	Percent Passing (%)
3/4" (19.0 mm)	
5/8" (16.0 mm)	

0.530" (13.2 mm)	
3/8" (9.5 mm)	
0.265" (6.7 mm)	
No. 4 (4.75 mm)	
No. 10 (2.00 mm)	
No. 16 (1.18 mm)	
No. 40 (.425 mm)	
No. 200 (0.075 mm)	

Or you may provide the gradation by uploading a file below or sending it to Mary Robbins at robbinm1@ohio.edu

What is the typical aggregate rate (lbs/SY) used for Otta seals?

What type of asphalt emulsion or binder is used for Otta seals?

Do you have written specifications for Otta seals, if so, may we have a copy?

Yes

No

Please provide a copy of your specifications of Otta seals here or through email at robbinm1@ohio.edu. Only one file can be uploaded through this survey, if you wish to share more than one file you can either upload a zip file of send them via email to Mary Robbins at the address listed above.

Ending Block

Please write anything else you'd like to add about chip seals, microsurfacing, slurry seals, or Otta seals with regard to aggregate supply, cost, quality, etc., in the space below.

14.3 Survey of Local Agencies, Responses

Question	Response #1	Response #2	Response #3	Response #4	Response #5
Agency type	County	City	County	Township	Township
Agency Name:	Tuscarawas County	City of Cleveland Heights	fayette county	Gasper Township Trustees	Windsor Township
Name:	Joe Bachman	Joe Kickel	Steve Luebbe	eric white	Robert Slusher
Position:	County Engineer	Capital Projects Manager	engineer	trustee	Trustee
Phone Number:	3303396648	216-291-2470	7403351541	937 533 9600	4402725795
Email Address:	tcejoe@yahoo.com	jkickel@clvhts.com	steve.luebbe@fayette-co-oh.com	ewlibertarian@yahoo.com	windsortwp04@yahoo.com
Have chip seals, microsurfacing, slurry seals or Otta seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?	Yes	Yes	Yes	Yes	No
Please select all applicable treatments that have been placed in your jurisdiction in the past 5 years.	Chip Seals	Chip Seals	Chip Seals	Chip Seals	
Are chip seals placed by: - Selected Choice	County/city crews	Contract	Contract	Contract	
In 2019, what was the approximate amount (SY or lane miles or tons) of chip seals placed in your jurisdiction?	90 lane miles	21,725	15 miles	3 miles + patching	
In general, how does the amount of chip seals placed in 2019 compare to previous years?	moderate decrease	slight increase	slight increase	about the same	
What was the average cost ($/ton or $/CY) of chip seal aggregate in 2019?	$14/ton	aggregate is inclusive to the price of a single chip seal	$1.20/SY for everything. we don't break out the cost for aggregate.	$6 a ton	
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Selected Choice	More ($/ton):	About the same as previous years	About the same as previous years	About the same as previous years	
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - More ($/ton): - Text					
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Less ($/ton): - Text					
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 1	gravel	ACBFS	limestone	limestone	

Question	Response #1	Response #2	Response #3	Response #4	Response #5
Agency type	County	City	County	Township	Township
Agency Name:	Tuscarawas County	City of Cleveland Heights	fayette county	Gasper Township Trustees	Windsor Township
Name:	Joe Bachman	Joe Kickel	Steve Luebbe	eric white	Robert Slusher
Position:	County Engineer	Capital Projects Manager	engineer	trustee	Trustee
Phone Number:	3303396648	216-291-2470	7403351541	937 533 9600	4402725795
Email Address:	tcejoe@yahoo.com	jkickel@clvhts.com	steve.luebbe@fayette-co-oh.com	ewlibertarian@yahoo.com	windsortwp04@yahoo.com
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 2	limestone	N/A	limestone		
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 1	#8	8	8's	#9	
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 2	#8	N/A	9's	57	
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 1	local quarry	LaFarge	quarry	local	
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 2	NW Ohio	N/A	quarry		
What is the typical aggregate rate (lbs/SY) used for chip seals?	25	22-25	20		
What type of asphalt emulsion or binder is used for chip seals?	HFRS-2	Refined Coal Tar RT-12 (ASTM D490)	hfrs-2p	Mc-3000	
Do you have written specifications for chip seals, if so, may we have a copy?	No	Yes	No	Yes	
Please write anything else you'd like to add about chip seals, microsurfacing, slurry seals, or Otta seals with regard to aggregate supply, cost, quality, etc., in the space below.	nothing	nothing	nothing	I have been very successful leveling and widening with a base coat of 301 asphalt, followed in a year with a full coat of chip seal, I have a bid Monday night @ 6:30 (very small this year) I have an extra packet I will snail mail you or possibly scan it....Many years ago I read a students master thesis on chip and seal I found on Google...me are committed to it as we are a rural Twp...Dr. Robbins, I also sent you an email asking about Gilsonite, hope it doesn't go to spam, sorry I wasn't more specific especially on the recycle	nothing

Question	Response #6	Response #7	Response #8	Response #9	Response #10
Agency type	County	Township	County	County	County
Agency Name:	Fulton County Engineers Office	Tuscarawas Township	Medina County	Lorain County Engineer's Office	Ashland County Engineer
Name:	Mike Burkholder	Denny Britton	Andy Conrad	Shaun Duffala	Edward J Meixner
Position:	Civil Technition	Road Foreman	County Engineer	Engineer IV	Ashland County Engineer
Phone Number:	419-335-3816	330-832-4337	330-723-9559	440-329-5586	419-282-4281
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	aconrad@medinaco.org	sduffala@loriancounty.us	emeixner@ashlandcounty.o
Have chip seals, microsurfacing, slurry seals or Otta seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?	Yes	Yes	Yes	Yes	Yes
Please select all applicable treatments that have been placed in your jurisdiction in the past 5 years.	Chip Seals	Chip Seals	Chip Seals	Chip Seals	Chip Seals,Microsurfacing
Are chip seals placed by: - Selected Choice	Contract	Contract	Contract	Contract	Contract
In 2019, what was the approximate amount (SY or lane miles or tons) of chip seals placed in your jurisdiction?	12	6 mile	74 lane miles	45 miles	+ 100 lane miles
In general, how does the amount of chip seals placed in 2019 compare to previous years?	about the same	about the same	about the same	about the same	about the same
What was the average cost ($/ton or $/CY) of chip seal aggregate in 2019?	$15,000 per mile		$80/ton	$35 / ton. We use #8 washed limestone	$19.58/ton
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Selected Choice	About the same as previous years		More ($/ton):	About the same as previous years	About the same as previous years
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - More ($/ton): - Text			slight increase		
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Less ($/ton): - Text					
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 1	limestone		slag	Limestone	Limestone

Question	Response #6	Response #7	Response #8	Response #9	Response #10	#10 (microsurfacing)
Agency type	County	Township	County	County	County	County
Agency Name:	Fulton County Engineers Office	Tuscarawas Township	Medina County	Lorain County Engineer's Office	Ashland County Engineer	Ashland County Engineer
Name:	Mike Burkholder	Denny Britton	Andy Conrad	Shaun Duffala	Edward J Meixner	Edward J Meixner
Position:	Civil Technition	Road Foreman	County Engineer	Engineer IV	Ashland County Engineer	Ashland County Engineer
Phone Number:	419-335-3816	330-832-4337	330-723-9559	440-329-5586	419-282-4281	419-282-4281
Email Address:	mburkholder@fultoncountyoh.com	tusctwp@sssnet.com	aconrad@medinaco.org	sduffala@loriancounty.us	emeixner@ashlandcounty.o	emeixner@ashlandcounty.org
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 2						
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 1	#8's		#8	8	#8s (Ashland 8s)	
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 2						
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 1			cleveland	Wagner (Sandusky)	National Lime & Stone, Bucyrus, OH	
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 2						
What is the typical aggregate rate (lbs/SY) used for chip seals?	.25 lbs /SY		20lbs/SY	22 lbs/SY	22 lbs/sy	
What type of asphalt emulsion or binder is used for chip seals?	SS1H		CRS-2 Latex Modified	CRS-2	We have used CM-90 (Asphalt Materials), MC 3000, HFRS2P, & CRS2P	
Do you have written specifications for chip seals, if so, may we have a copy?	Yes		No	No	Yes	No
Please write anything else you'd like to add about chip seals, microsurfacing, slurry seals, or Otta seals with regard to aggregate supply, cost, quality, etc., in the space below.	do not care for the slurry seal	nothing	file:///home/wp/highway contract forms/2020/Chip Seal/Chip & Seal documents.doc Here is our chip seal bid document. This screen would not let me go back.	We still utilize the ODOT 1997 specification (Item 409). We find it better to spec out the emulsion and stone separate instead of bidding them together as is shown in the more current spec books.		

Question	Response #11	#11 (microsurfacing)	Response #12	#12 (microsurfacing)	Response #13
Agency type	County	County	County	County	County
Agency Name:	Wayne County Engineer's Office	Wayne County Engineer's Office	Crawford County Engineer	Crawford County Engineer	Huron County
Name:	Ryan P. Marthey, P.E.	Ryan P. Marthey, P.E.	Jason Long	Jason Long	
Position:	Highway & Drainage Engineer	Highway & Drainage Engineer	Administrator	Administrator	
Phone Number:	330-621-1263	330-621-1263	419-562-7731	419-562-7731	
Email Address:	rpm@wayne-county-engineer.com	rpm@wayne-county-engineer.com	jasonl@crawfod-co.org	jasonl@crawfod-co.org	
Have chip seals, microsurfacing, slurry seals or Otta seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?	Yes	Yes	Yes	Yes	Yes
Please select all applicable treatments that have been placed in your jurisdiction in the past 5 years.	Chip Seals,Microsurfacing	Chip Seals,Microsurfacing	Chip Seals,Microsurfacing	Chip Seals,Microsurfacing	Chip Seals
Are chip seals placed by: - Selected Choice	Both county/city crews and contract	Contract	Contract	Contract	Contract
In 2019, what was the approximate amount (SY or lane miles or tons) of chip seals placed in your jurisdiction?	zero	0	100,000sy	0	120 miles
In general, how does the amount of chip seals placed in 2019 compare to previous years?	moderate decrease	moderate decrease	about the same	moderate decrease	about the same
What was the average cost ($/ton or $/CY) of chip seal aggregate in 2019?	$25/ton		18.00		1.20 SY
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Selected Choice	About the same as previous years		About the same as previous years		About the same as previous years
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - More ($/ton): - Text					
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Less ($/ton): - Text					
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 1	limestone		limestone		limestone

Question	Response #11	#11 (microsurfacing)	Response #12	#12 (microsurfacing)	Response #13
Agency type	County	County	County	County	County
Agency Name:	Wayne County Engineer's Office	Wayne County Engineer's Office	Crawford County Engineer	Crawford County Engineer	Huron County
Name:	Ryan P. Marthey, P.E.	Ryan P. Marthey, P.E.	Jason Long	Jason Long	
Position:	Highway & Drainage Engineer	Highway & Drainage Engineer	Administrator	Administrator	
Phone Number:	330-621-1263	330-621-1263	419-562-7731	419-562-7731	
Email Address:	rpm@wayne-county-engineer.com	rpm@wayne-county-engineer.com	jasonl@crawfod-co.org	jasonl@crawfod-co.org	
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 2	gravel				
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 1	#8		8		#8
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 2	#8				
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 1	parkertown		quarry		Sandusky Quarry
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 2	fiekert s&g				
What is the typical aggregate rate (lbs/SY) used for chip seals?	18-22 lbs/SY		23/sy		22
What type of asphalt emulsion or binder is used for chip seals?	crs-2		RS-2		CRS-2
Do you have written specifications for chip seals, if so, may we have a copy?	Yes	No	No		No
Please write anything else you'd like to add about chip seals, microsurfacing, slurry seals, or Otta seals with regard to aggregate supply, cost, quality, etc., in the space below.	Updated Specs and Bid Blank for Addendum 1.pdf				

Question	Phone Interview #1	Phone Interview #2	Phone Interview #3	Phone Interview #4	Phone Interview #4
Agency type	County	County	County	City	City
Agency Name:	Washington County	Auglaize County	Butler County	City of Lancaster	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Greg Hintz	Greg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent	Superintendent
Phone Number:		419-739-6520	513-785-4143	740-687-6668	740-687-6668
Email Address:	wce@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org		
Have chip seals, microsurfacing, slurry seals or Otta seals been placed in your jurisdiction in the past 5 years, either by in-house forces or by contract?	Yes	Yes	No, Stopped placing chip seals 5 years agp due to higher traffic volumes on their routes. Have placed mico-surfacing in the past as well. Still have program for townships (placed 2 chip seals in 2020 in subdivisions). Have done slurry seal in 2 townships but not in county	Yes	Yes
Please select all applicable treatments that have been placed in your jurisdiction in the past 5 years.	Chip Seals Micro surfacing placed years ago and not happy with performance	Chip Seals	See above	Chip seals	Micro-surfacing
Are chip seals placed by: - Selected Choice					
In 2019, what was the approximate amount (SY or lane miles or tons) of chip seals placed in your jurisdiction?	70 lane miles	In 2020 placed 6000 tons of aggregate and 250,000 gallons of emulsion		1500 tons of aggregate per year	60,000 - 70,000 SY/YR (placed 85,000 SY in 2020)
In general, how does the amount of chip seals placed in 2019 compare to previous years?	about the same	about the same (same program in 2020 as in 2019)			
What was the average cost ($/ton or $/CY) of chip seal aggregate in 2019?	Limestone: $22-24.50/ton River gravel: $12-15/ton	$11/ton from quarry (total cost of chip seal well under $15,000/mile)		$24/ton delivered on-site	not sure of agg cost, micro-surfacing costs between $290 and $349/SY depending on size of project
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Selected Choice					
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - More ($/ton): - Text					
How does the average cost of chip seal aggregate in 2019 compare to previous years? If known, please provide the approximate cost difference. - Less ($/ton): - Text					
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 1	Limestone	limestone		limestone	Limestone

Question	Phone Interview #1	Phone Interview #2	Phone Interview #3	Phone Interview #4	Phone Interview #4
Agency type	County	County	County	City	City
Agency Name:	Washington County	Auglaize County	Butler County	City of Lancaster	City of Lancaster
Name:	Roger Wright	Doug Reinhart	Dale Steward	Greg Hintz	Greg Hintz
Position:	County Engineer	County Engineer	Construction Deputy	Superintendent	Superintendent
Phone Number:		419-739-6520	513-785-4143	740-687-6668	740-687-6668
Email Address:	wce@wcgov.org	dreinhart@auglaizecounty.org	stewardd@bceo.org		
What aggregate is utilized for chip seals and where is it sourced from? - a. Aggregate Type (e.g. limestone, gravel, slag, etc.): - Aggregate 2	River Gravel				
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 1	#8	#8		#8	#10
What aggregate is utilized for chip seals and where is it sourced from? - b. Size (e.g. #8s, #9s, #57s, #67s, etc.): - Aggregate 2	#8				
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 1					
What aggregate is utilized for chip seals and where is it sourced from? - c. Source: - Aggregate 2					
What is the typical aggregate rate (lbs/SY) used for chip seals?	25 lb/SY	22 lb/sy		22- 24 lb/sy	
What type of asphalt emulsion or binder is used for chip seals?	MWS-90 and MWS-90P	HFRS-2P @ 0.42 gal/SY		RS-2P (from 2019 to present, prior to that used RS-2)	Cationic emulsion
Do you have written specifications for chip seals, if so, may we have a copy?					
Please write anything else you'd like to add about chip seals, microsurfacing, slurry seals, or Otta seals with regard to aggregate supply, cost, quality, etc., in the space below.	Cost of chip seal is $14-15k/mile	cost of chip seal is well under $15,000/mile		Planning on teaming with Asphalt Materials to place RAP chip seal and RAP micro surfacing hopefully next year	Planning on teaming with Asphalt Materials to place RAP chip seal and RAP micro surfacing hopefully next year

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