



**White Paper on
Optimum Slurry Seal Products
Used in Southern California**



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Overview and Executive Summary

Emulsion slurry seals are stable mixtures of emulsified asphalt, mineral aggregate, water, set control agents and latex. There are various types of these slurry seals that vary by type of asphalt emulsions used and the mixture design (proportions of emulsions to aggregates). The quality and service life of slurry seals varies depending on the components used, the mixture design, and the method of construction. In addition, since slurry seals are used on existing pavements, the impact of the placement of these slurries on the environment, on the interruption to traffic, and convenience of the road users can vary and should be considered.

This report is written to highlight the benefits of rubberized slurry seals that utilize structurally modified asphalt binders with recycled tire rubber to deliver superior performance in terms of pavement surface characteristics, more durable service life, and less environmental impact and less inconvenience to road users.

Rubberized Emulsion Aggregate Slurry (REAS) is not a new product; it has been used for more than 20 years by many cities and municipalities in Southern California. This report covers the following aspects of this effective pavement preservation technology:

1. Background about why pavement preservation, and Slurry Seal treatments, can improve the return on the investments of roads.
2. The optimization of Slurry Seal production and impact by using a special combination of asphalt binder modified with optimum amount of recycled tires.
3. To compare this product to the unmodified products used in the market as a reference to its success.

The report shows that REAS products can provide excellent *benefit to cost value* and contributed to preserve a vast portion of the Southern California road network. It also shows that REAS has a positive impact on the waste management efforts in Southern California by using recycled tires in an effective engineering method.

The application of this product is also shown to be environmentally friendly and results in minimal inconvenience to the community through the use of specialized application equipment that produces almost zero emissions, low noise emissions, and un-noticeable odor during application.

Pavement preservation in livable communities is very challenging due to the sensitivity of residents to noise and hydro-carbon emissions (smell). Optimum solutions are available and Rubberized Emulsion Aggregate Slurry (REAS), as documented in this report, offers solutions that can be adopted today.

Background

Why we need pavement preservation, and why use Emulsion Aggregate Slurry Seals?

Road pavements are primarily constructed to provide a smooth and safe surface for travelers and additionally to provide a protection of the natural ground from heavy load applied by vehicles, in particular loaded trucks. With time pavements age and deteriorate due to the high volume of heavy trucks and extreme climate conditions. Most pavements have sufficient load bearing capacity but not adequate surface characteristics. Pavement surface characteristics preserve the structural integrity, and provide skid resistance and riding comfort for users. Pavement preservation stretches the period of life a pavement remains in serviceable condition for the traveling public. The benefit is an improved and stable condition level at a lower unit cost per lane mile (Ref. 1, 2014).

The preservation surface treatments for pavements do not improve the bearing capacity, but can improve serviceability function (condition) and delay costly rehabilitation programs. When applied on the right pavement at the right time, these surface treatments can save highway agencies up to seven dollars in delayed rehabilitation cost for every one dollar spent on pavement preservation treatment (Chan, et al., 2011). Therefore pavement preservation pays off in both the short and long term.

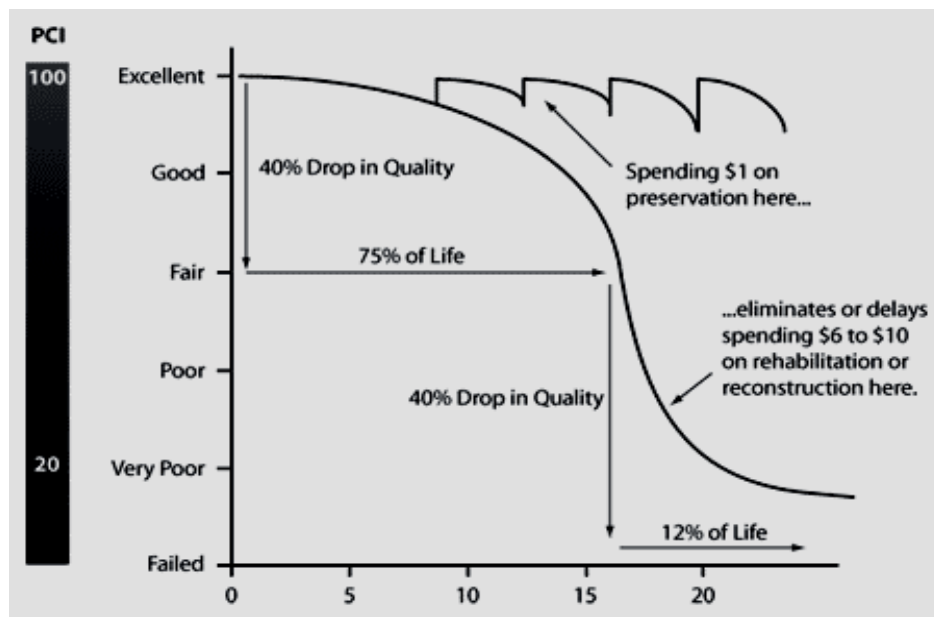


Figure 1. Pavement Preservation benefits (example). (PCI = Pavement Condition Index) PCI can be kept at high quality for extended life with Pavement Preservation Treatments such as Slurry Seals is used (Ref. 2, 2014)

As road agencies that are strapped for cash look for ways to optimize their limited dollars, many are taking a much closer look at the practice of pavement preservation. Over the last two decades, Highway Agencies have embraced pavement preservation programs as the best cost-effective approach for extending pavement lives, preserving structural capacity and providing quality service to the traffic when funds are limited.

As indicated by the National Center on Pavement Preservation- FP2, “pavement preservation techniques are being promoted by the Federal Highway Administration (FHWA) and the American Association of State Highway & Transportation Officials (AASHTO) as cost-effective and environmentally sustainable strategies designed to extend the life of existing pavements before they deteriorate substantially” (Ref.- 2).

Slurry seal has become widely accepted pavement preservation surface treatments over the last three decades. It is a mixture of asphalt emulsion, well-graded fine aggregate, mineral filler, and water (Ref. 3, 2008). It is applied at room temperature or slightly above on the prepared surface of the existing pavement in relatively thin layers. The water evaporates with time leaving behind a product with surface characteristics resembling those of hot mix asphalt (HMA) concrete. Slurry seal can be applied to improve surface characteristics and seal all cracks on the surface. High quality slurry seals can be produced using high quality materials such as polymer modified cationic emulsions, special emulsifiers and well-graded fine aggregate (Ref. 4, 2010).

Rubberized Emulsion Aggregate Slurry (REAS)

Can pavement preservation with slurry seals be also a solution to recycling used tires?

One of the effective methods for modifying conventional asphalts is adding Ground Tire Rubber (GTR). GTR is produced from used vehicle and truck tires by shredding or cryogenic crushing to produce crumbs of rubber particles that can be mixed and dispersed in asphalt. The benefits of modifying asphalt with GTR includes environmental sustainability (recycling used tires in an effective application), and significant improvements of asphalt properties used in road applications, such as slurry seals.

Used tires are considered one of the most challenging solid wastes to deal with today due to their ability to burn and cause fires, and due to the fact they are not bio-degradable. Recycling of used tires after grinding and mixing with asphalt has been successfully used in pavements for many years. Although there are different opinions about the best conditions for using GTR, most specialists agree that the use of GTR in asphalt has positive impact on pavement preservation programs, such as extending the life of pavement structures. For many years the City of Los Angeles has used rubberized emulsions on low traffic roads and has found the product to meet the target service with no problems. Asphalt rubber, or rubberized asphalt is also used in many regions in the United States and around the world successfully in building pavements.

Emulsion Aggregate Slurry is one of these successful applications that has been produced, applied, and monitored for more than 30 years on various parts of road network in the State of California. Rubberized Emulsion Aggregate Slurry (REAS) is a special product that adds to the benefits of recycling and improved asphalt properties, an environmentally friendly method for application. Because the product contains water and a special emulsifying chemical, it can be transported and applied at ambient, or slightly warmer temperatures.



This eliminates the need to use energy to maintain the asphalt at high temperature, and more importantly, eliminates smell or hydrocarbon emissions, commonly noticed with use of heated asphalts. The only emission from rubberized emulsion is water vapor that can hardly be noticed or smelled.

This type of slurry is better for workers, better for community living around the streets being repaired, can save cost for the department of roads and streets, and can make roads last longer.



Slurry seals can be mixed on truck or in a central mix plant, where it can be controlled more accurately and produced more consistently. REAS is a unique mixture of a rubber modified emulsion, (produced by combining a structurally modified asphalt with selected amount and size of recycled rubber crumbs), with aggregate, water and set control

chemical and stabilizers. It is manufactured in a Central Mix Plant and supplied to the jobsite in a finished slurry mixture for application to the pavement surface.

The crumb rubber used in this slurry is selected to be free from fabric, wires and other contaminants, dry and free flowing, and have a gradation of 100% passing the # 16 (1.18 mm) sieve, 95% passing the # 20 (0.90 mm) sieve and a maximum of 1% passing the # 200 (0.075 mm) sieve.



The asphalt emulsion used in the REAS is a Rubberized Polymer Modified Emulsion (RPME) composed of emulsified asphalt, crumb rubber, and other additives. Its quality is controlled to meet the following requirements as specified in the Standard Specification for Public Works (also called the Green Book). These requirements are chosen because it has been shown that materials meeting these requirements are proven to give long lasting and effective properties. Table 203-3.4.4.2(A) is reproduced in Table 1 below to show the limits required for the various properties. These values of Viscosity and Softening point assures good workability of emulsion to allow uniform spreading, yet after water evaporates, the Residue, will have enough resistance to warm weather and traffic loading.

Table 1. Requirements for the composition of Rubberized Polymer Modified Emulsions
(Reproduced from the Standard Specifications of Public Works – 2012 Green Book)

TABLE 203-3.4.4.2 (A)

Tests	ASTM Test Method	Requirement	
		Min.	Max.
Viscosity, 77°F (25°C), Brookfield, Model RVT #6 Spindle @ 10 RPM (Centipoise) @ 60 sec.	D 2196	4,000	12,000
Residue by Evaporation % (including fillers)	D6934	50	55
Sieve Test (% retained on No. 20 (850 µm) sieve)	D6933	---	2.0 ¹
Penetration of Residue, 77°F (25°C), 0.1 mm,	D 5	15	30
Solubility of Residue	D 2042	75	---
Weight lbs/gallon (g/L) 77°F ± 1°F (25°C ± 5°C)	D 1475	8.33 lbs/gal (1000g/L)	8.75 lbs/gal (1050g/L)
Asphalt Content ²	----	40	----

1. Sieve test of original emulsion is 0.10 max.
2. Asphalt Content shall be determined by multiplying Residue by Evaporation by Solubility of Residue.

The aggregate used to mix with the rubberized emulsion are also well controlled to be 100% crushed rock and to have good level of soundness so that they can withstand weathering from heavy loading and cycles of cool and warm weather. The size of aggregates is also controlled and varied to produce four types of REAS: Fine, Type I, II and III. These types vary by the maximum particle size of the crushed rock and the combination of sizes. Type “Fine” is produced with the smallest size rock while the Type III has the largest size. Maximum size and combination of rock sizes are needed to deliver the needed product for the target thickness and preferred texture of the surface. More texture is needed for higher speed streets or roads to give better skid resistance (safety). Road and Street departments can select the type and thickness required based on condition of roads and the economics of the products. Table 2 reproduced from the Green Book shows the requirements for aggregates and the gradations.

Table 2. Requirements for the aggregate used in the Various Types of Slurry Seals
(Reproduced from the Standard Specifications of Public Works – 2012 Green Book)

TABLE 203-5.3.1 (A)

Tests	ASTM Test Method	Requirements
Percentage Wear at 500 Revolutions ¹	C131	40% Maximum
Sand Equivalent	D2419	55 Minimum
Soundness(5 Cycles) ¹	C88	15% Maximum

1. To be run on the material retained on the No. 4 (4.75 mm) sieve graded from the source.

TABLE 203-5.3.2 (A)

Sieve Size	Percentage Passing Sieves							
	Type Fine		Type I		Type II		Type III	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
3/8 inch (9.5 mm)	100	---	100	---	100	---	100	---
No. 4 (4.74 mm)	100	---	100	---	90	100	70	90
No. 8 (2.36 mm)	95	100	90	100	65	90	45	70
No. 16 (1.18 mm)	75	92	65	90	45	70	28	50
No. 30 (600 µm)	50	75	40	60	30	50	19	34
No. 50 (300 µm)	35	50	25	42	18	36	12	25
No. 100 (150 µm)	15	30	15	30	10	24	7	18
No. 200 (75 µm)	10	20	10	20	5	15	5	15

Benefits of REAS Made with RPME as Compared to Other Products

Aggregate slurry seals can be classified in two products:

- 1) Rubberized Emulsion Aggregates Slurry (REAS), and
- 2) Conventional Emulsion Aggregates Slurry (EAS)

Similar to other construction materials, there are products that meet the minimum required specifications but vary in cost and composition. To verify quality and competitiveness, it is logical and important to compare products on technical basis to evaluate the potential cost/benefit relation.

The comparison is based on three important characteristics:

- (i) composition of emulsion,
- (ii) amount of emulsion used, and
- (iii) rate of setting.

(i) **Composition:** It is well recognized that the performance of slurry seals depends on the composition of emulsion used. Table 3 compares the minimum emulsion residue (asphalt binder amount after water evaporates) and the minimum rubber required in the production of the emulsions. These values are taken from the specifications of the products as supplied by the producers, or as listed in the Green Book. Three important observations can be made:

- The REAS specifications require a minimum of 15.0 % to 26% residual asphalt content, depending on the type of slurry. This is more than double the minimum amount required for EAS. This difference in residual asphalt will provide a thicker film of binder to protect the aggregates and give more service life as compared to other products. It is also known that oxidative aging of asphalt binders is highly related to the film thickness. With almost double the film thickness of binders in the REAS, deterioration of the slurry caused by aging of binders in REAS will be much slower and less damaging than for the other products.

Table 3. Comparison of Emulsions' composition used in Rubberized (REAS) and Conventional (EAS) Slurries *

Minimum <u>Residue</u> Asphalt Content by Dry Aggregate Weight		
	Rubberized Slurry REAS	Conventional Slurry - EAS
Type I	26.00%	10.00%
Type II	17.00%	7.50%
Type III	15.00%	6.50%
Rubber Content by % Dry Aggregates ¹		
	Rubberized Slurry REAS	Conventional Slurry - EAS
Type I	3.6-4.4	0.00
Type II	2.1-3.1	0.00
Type III	1.8-2.7	0.00
¹ :Crumb rubber content shall be 66 - 78 grams/liter, and Latex shall constitute a minimum of 2 percent by weight of RPME. Section 203-3.4.4.1.		

*:Values are taken from SSPWC 2012 Edition Tables 203-5.5.2.2(A).

- Amount of recycled rubber incorporated in the asphalt binder is known to have significant effect on rheological properties of binders. It is known that rubber increases viscosity and elasticity, allowing slurry seals to perform much better by resisting flow under high pavement temperatures. It is also known that rubber increases toughness and strain tolerance at low pavement temperatures making slurries more resistance to shrinkage cracking and to fatigue cracking.

It is thus evident from the above comparison that REAS is a good product that last several years. The higher residue required, and the recycled rubber used, are the reason why REAS is showing such success in many regions in the country, and in particular in the State of California.

- (ii) **Emulsion amount and mixture design of slurry seals:** The proportioning of the emulsion to aggregates is an important design aspect of slurry seals. Higher emulsion content ensures better coating of the aggregates and thicker binder films that can provide better protection to the aggregates. This increased protection results in more resistance to moisture damage in wet climates, resistance to raveling under traffic action, and resistance to oxidative aging in warm climates. It is also believed that thicker films will reduce stress/strain in binder films allowing more resistance to fatigue cracking under traffic. Table 4 shows the minimum required emulsion content for the different slurries.

Table 4. The Range in Asphalt Emulsion Content Required in REAS and EAS*

Minimum Asphalt <i>Emulsion</i> Content by % Dry Aggregate Weight		
	Rubberized Slurry REAS	Conventional Slurry – EAS
Type I	50-57	17-20
Type II	33-40	14-18
Type III	28-35	11-15

*: Values are taken from SSPWC 2012 Edition Tables 203-5.5.2.2(A).

The following observations can be made:

- Based on the minimum residue required (Table 3 above), it is estimated that the REAS after breaking and setting will contain residual binders almost 2.4 times (140 % more) than the conventional EAS. It is thus not logical to expect same service lives of these products. Although both products contain asphalt binder, a difference of 140 % in residual binder content, with the inclusion of recycled rubber in the REAS make these products very different.

(iii) **Setting Rates, Cost and Life Expectancy:** Other products such as the conventional slurry, mostly use a cationic emulsion, that is expected to set faster with all aggregates, more consistently, have a wider temperature application range, and costs about 25 % less than other rubberized slurry seals. (Brochure from Pacific Emulsions). However, there are some important technical realities that need to be recognized and considered in comparing cost and setting rates:

- Based on the analysis presented in sections (i) and (ii), it is clear that the cost reduction is possible only because there is less residual asphalt binder and less recycled rubber content. Considering the fact that there is more than 140% more residual binder and recycled rubber could imply that the other products cost should be only a fraction of the production cost of REAS.
- Rate of setting, consistency, and application temperature range are known to depend on many factors, not only the charge of the particle. Reviewing the TRB Circular 102 on asphalt emulsions, published in 2006 (Ref 5, 2006), Table 5 includes some of the important factors that are considered to be important and how they are related to this comparative analysis.

Table 5. Comments on Setting Rate and Consistency

Statements from TRB Circular 102	Comments about REAS as Compared to other products
"Increasing the asphalt content will break an emulsion faster while decreasing the content will slow the set down."	It is important to note that REAS has much higher asphalt content than the EAS. Thus it is expected to set faster.
"Ambient and emulsion temperatures. Higher temperatures will cause an asphalt emulsion to break faster."	Selecting the appropriate temperature for application could be more important than using a different charge on the emulsion. Claiming that at all conditions a Cationic emulsion will set faster is not always a valid assumption.
"Asphalt emulsion particle size and distribution. The finer the asphalt cement droplets size and the smaller dispersion increase setting time of an emulsion."	This confirms that charge of the emulsion is not the only factor and there are many other factors that affect setting rate.
"The use of additives can increase or decrease the breaking of asphalt cement. In applications such as slurry seals, hydrated lime or Portland cement is added to set the mixture faster."	REAS include the use of additives, such as cement to adjust the setting rate to an optimum time and conditions.
"Some aggregates, like carbonates, and fillers, like cement, may neutralize acid in cationic emulsions causing the pH to rise and the emulsion to be destabilized. Anionic emulsions may be destabilized by soluble multivalent ions. In practical situations too early coalescence of the asphalt droplets can hinder final curing by skin formation reducing the evaporation of water."	Using anionic emulsion could reduce the risk of destabilization and allow more workable product.

Calculating Economic Benefits of Preventive Maintenance

The Bureau of Street Services (BSS) of the City of Los Angeles has used REAS for a number of years. Based on the documented performance on the City road network, an economic analysis was conducted in 2003 to determine the cost effectiveness on pavement life, using REAS as a preventive surface maintenance treatment on asphalt surface roads (Ref. 6, 2003).

The following assumptions were made in the analysis with regard to costs:

- (1) Cold mill 2.5" of asphalt - \$1.50/sy
- (2) 2.5" asphalt overlay - \$28/ton in place
- (3) Cost of REAS - \$1.65/gallon

Based on the above listed cost estimates, and the typical maximum service life of an overlay of 20 years, the annual cost without preventive maintenance can be calculated to be equal to \$ 0.265/sy/year, as follows:

$$(1) \text{ Overlay Cost} = ((2.5/12 \text{ inch}) \times 1\text{sf}) \times (145\text{lb}/\text{ft}^3) \times (1 \text{ ton}/2000 \text{ lb} \times \$28/\text{ton}) \\ = \$0.42/\text{sf} \times 9\text{sf}/\text{sy} = \$3.81/\text{sy}$$

$$\text{Therefore, the average annual Cost} = \text{Mill cost } (\$1.50/\text{sy}) + \text{Overlay cost } (\$3.81/\text{sy}) \\ = (\$5.31/\text{sy})/20 \text{ years} = \mathbf{\$0.265/\text{sy}/\text{year}}$$

$$(2) \text{ The Cost of each REAS application} = ((\$1.65/\text{gallon}) \times (1 \text{ gallon}/22\text{sf})) \\ = \$0.075/\text{sf} \times 9\text{sf}/\text{sy} = \$0.675/\text{sy}$$

Based on the cost analysis identified in (1) and (2), the minimum increase in life required to make the REAS as cost effective as Mill and Overlay can be calculated as follows:

$$= \text{REAS Cost} / \text{Mill \& Overlay Cost} = (\$0.675/\text{sy}) / (\$0.265/\text{sy}/\text{yr}) \\ = 2.53 \text{ years} \sim \mathbf{2.5 \text{ years}}$$

The study conducted by the City of Los Angeles and private consultants (Ref. 6, 2003) indicates that the Bureau of Street Services “has been involved with REAS application since 1993.” It also indicates that the Standards Division Asphalt Laboratory has regularly conducted daily quality control testing of REAS for several years, and the experience from the use of REAS shows an increase in pavement life of **4 years**. In other words the average annual cost of REAS is $(\$0.675/4.0 \text{ years} = \$0.169/\text{sy}/\text{year})$, which is approximately **36 % saving** $((\$ 0.265/\text{sy}/\text{year} - 0.169/\text{sy}/\text{year})/ \$ 0.265/\text{sy}/\text{year} * 100 = 36.23 \%)$, as compared to typical rehabilitation using mill and overlay $(\$0.265/\text{sy}/\text{year})$.

It should also be mentioned that the City of Los Angeles concluded that “In addition to the cost savings realized by the proper application of REAS, several other benefits are also achieved. Safety is enhanced due to increased skid resistance, and repairs to moderately worn street surfaces. The final result is an aesthetically appealing uniform black color, resembling a new black top surface.”

As a result the successful use of REAS, its specification was incorporated into the Standards Specifications for Public Works Construction, in 1998.

Concluding Remarks

This report is written to explain the benefits of using rubberized aggregate slurry seals for preservation of pavements' conditions. Based on observations reported and detailed analysis of the characteristics of two main commonly used Slurry Seal Products, the following concluding remarks can be stated:

- Pavement preservation is widely recognized as a good investment in maintaining surface characteristics of pavements while protecting the structural integrity. Many estimates by experts independent of suppliers indicate a dollar spent on preservation can save 6- 10 dollars in maintenance in the long term.
- Rubberized Emulsion Aggregate Slurry (REAS) can not only preserve pavements, but also preserve the environment. Using recycled tires help solve the solid waste issues and improve the performance of pavement treatments.
- The economic analysis shown in Ref. 6, 2003 concluded that REAS application is cost effective if pavement life is extended beyond 2.5 years. In addition, "Experience from the use of REAS in the City of Los Angeles demonstrated an increase in pavement life of 4 years. The study also document other secondary benefits such as protect the pavement surface and providing better ride-ability and safety (skid resistance).
- Road maintenance does not have to be noisy and smelly. Using Rubberized Emulsions make this necessary activity friendlier to communities and to the environment.
- REAS products are a much better choice than conventional emulsion (EAS) products in terms of durability and expected service life. REAS are more expensive than EAS because they include more residual asphalt and include recycled rubber that improves service life.
- REAS products are not created equal and cannot be fairly compared without consideration of technical details. There could be significant differences in the composition of emulsions and the proportions used in the mixture designs. Although some REAS products can be produced at lower cost. The reduction in cost however could be derived from significant reduction in binder content, and recycled rubber content. This practice is not a good idea because such reductions are known to cause reduction in quality and cause inferior performance in terms of resistance to moisture, traffic, and oxidation.
- Pavement preservation using rubberized emulsions is beneficial for users, for the road authorities trying to use limited funding effectively, and for our environment. Designs of slurry seals can vary, but benefits are proportional to the design and composition.

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