Asphalt Rubber Chip Seal Evaluation and Comparison of Other Binder Types

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ABSTRACT: *Asphalt Rubber Chip Seals (ARCS) have been used as an effective Preventative Maintenance strategy by the California Department of Transportation (CALTRANS) for over 35 years, not only on minor projects but also on major roadways where both high truck traffic, high ambient and pavement temperatures have been prevalent. Due to flushing/bleeding in the wheel paths on one particular project in Imperial County, California, Caltrans placed nine test sections using two different asphalt rubber (AR) binders, modified binders designated as a PG 70-22TR, and a polymer modified asphalt rubber binder. Various ½ inch (12.5 mm) coarse aggregate gradings were utilized, with one ½ inch (12.5 mm) gradation providing a more uniform one size aggregate. Various binder spread rates and aggregate spread rates were also evaluated. The asphalt rubber binders were designed to use 22% crumb rubber modifier (CRM) content (17 % scrap tire crumb rubber, 5 % high natural crumb rubber), asphalt modifier, and two base stock asphalts, AR 4000 and PG 70-10. The PG 70-22TR binders were designed utilizing 8% and 5.5% scrap tire crumb rubber and the polymer modified asphalt rubber binder was designed to use 16 % scrap tire crumb rubber with 2 % polymer. Key concepts that were developed and evaluated included the use of polymers, low and high percentages of CRM content, and the performance of the binders under extreme climatic conditions and traffic loading. This paper* *provides an evaluation and comparison of nine test sections and rates their performance over a period of three to five years.*

KEY WORDS: *pavement preservation, preventive maintenance, asphalt rubber chip seals, crumb rubber modified binders*

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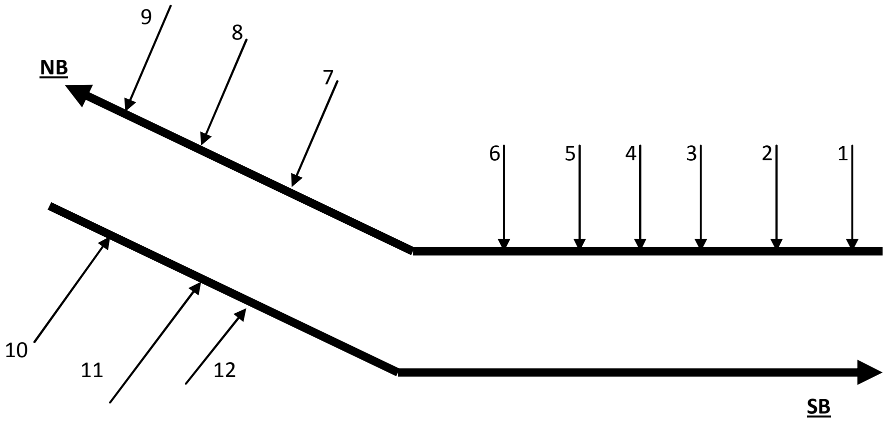
1. Introduction

1.1 Background

Asphalt rubber chip seals have been used by Caltrans since the 1970s. They have the advantage of resisting reflective cracking over conventional chip seals. However, it is very challenging to apply asphalt rubber chip seal under extreme weather and heavy traffic conditions. For example, an ARCS warranty project placed on State Route 86 in Imperial County (PM 37.3 to 43.3) on September 16-17, 2003. The truck lane of this project experienced flushing and rutting in the northbound number 2 lane within 6 months after construction [1]. A field review of the Imperial SR 86 project was performed along with other projects on I-8 in Imperial County and Kern SR 58 in District 6 during March 2005. The purpose of these field reviews was to assess the type and extent of the distress on these projects. A final report titled "Review and Evaluation of Asphalt Rubber Chip Seals" was issued on October 17, 2005 [1]. The results of this study recommended that the current specifications used for asphalt rubber chip seals in hot climates, placed on significant grades or under heavy truck traffic, needed to be modified to prevent bleeding and flushing.

In order to improve the chip seal applications under extreme conditions, nine test sections were placed on northbound SR 86 in Imperial County in high traffic areas with extreme temperature variations. The average high temperature for a three year period in the summer is 40.6^{o}C (105^{o}F) with an average low of 5^{o}C (41^{o}F) at night in the winter. The average daily traffic is in excess of 9,500 vehicles, with over 3,350 of the vehicles being heavy trucks. A two phase test was conducted by Caltrans. Phase 1 constructed six test sections from PM 28.4 to 30.7 on SR 86 in the northbound direction and in lane number 2. Phase 1 test sections were placed in May of 2005 with different base binder types for asphalt rubber, binder application rates, and gradations. Phase 2 constructed another six test sections (7 – 12) with different modified binders in September 2007. Only test sections 7 through 9 will be compared to test sections 1 through 6, as all were placed in the northbound direction under the same traffic loading conditions.

A final report for the construction and evaluation of test sections 1 through 6 was issued on September 9, 2008 [2]. The schematic layout of the Phase 1 AR test sites (Test Sections 1-6) along with subsequent Phase 2 tests sites for modified binders (Test Sections 7-12) is shown in Figure 1.



Test Section #1 - NB-86 PM 28.45	Test Section #7 - NB-86 PM 31.40
Test Section #2 - NB-86 PM 28.83	Test Section #8 - NB-86 PM 31.88
Test Section #3 - NB-86 PM 29.22	Test Section #9 - NB-86 PM 34.70
Test Section #4 - NB-86 PM 29.60	Test Section #10 - SB-86 PM 34.40
Test Section #5 - NB-86 PM 30.00	Test Section #11 - SB-86 PM 33.80
Test Section #6 - NB-86 PM 30.42	Test Section #12 - SB-86 PM 33.33

Figure 1. Layout of Test Sections on SR 86 (Northbound direction has the heavier traffic.)

1.2 Objective

The objective of this paper is to summarize the results and compare the performance of the northbound test sections 1 through 9, considering the effect of the following factors on asphalt rubber chip seal performance: type of binder, aggregate size, application rates, and coating on the aggregate. The performance of the southbound test sections (sections 10-12) is also reported, but they are not compared to the northbound test sections due to the lighter traffic loading conditions associated with Route 86.

2. Materials and Application Rates

The types of binders used in the two phase test sites include:

- **Asphalt rubber.** These are field blends and were used in the first test or in test sections 1-6. This is the traditional asphalt rubber that has been used in California since the 1980's and contains at least 18% CRM, which was later revised to contain a minimum of 20% CRM. The product used in the asphalt rubber test site contained a minimum of 22% CRM.
- **Modified binder (PG-PM).** Initially, the modified binders required less than 10% CRM, but now the PG 76-22 TR requires a minimum of 10% CRM; while the PG 76-22 PM has no minimum CRM content. The Paramount Petroleum product used on the project was graded out to be a PG 70-22 TR (PG 73-22 TR actual) (110 PAV) and contained 5.5% CRM with 3% polymer. This terminally blended product was utilized on test sections 8, 11, and 12.
- **Rubber asphalt binder (RAB).** These are field blended modified binders using a finer rubber and a polymer allowing it to be e PG Graded. The International Surfacing Systems products used in the test section number 7 and 10 were graded at PG 76-22 TR (PG 79-22TR actual) and PG 82-16 (100 PAV), respectively and contained 8% CRM with 3% polymer.
- **Polymer modified asphalt rubber (PMAR).** This field blended product is made like a field blended asphalt rubber, but contains 16 % CRM and 2% polymer. Because it contained a coarser rubber, it could not be graded using the PG system. This binder was used in test section 9 and has not been approved for use by the Caltrans binder committee to date.

Table 1. *Summarizes the materials and application rates for test sections 1 to 12.*

Table 1 Description of Materials and Design Application Rates

Test Section	Lane # 2 Direction NB/SB	Binder Type AR/MB	Application Rate (Actual)	Aggregate Gradation/ Size mm/inch	Pre-coated (Yes/No)	Application Rate 40lb/yd^2 21.7kg/m^2 Target
1[(6)]	NB	AR (AR 4000 Base Stock)	2.26 l/m^2 0.50 g/yd^2	12.5 mm ½ inch	Yes	21.7 kg/m^2 40 lb/yd^2
2[(6)]	NB	AR (AR 4000 Base Stock)	2.26 l/m^2 0.50 g/yd^2	12.5 mm ½ inch Coarser Gradation	Yes	21.7 kg/m^2 40 lb/yd^2
3[(6)]	NB	AR (PG 70-10 Base Stock)	2.26 l/m^2 0.50 g/yd^2	12.5 mm ½ inch Coarser Gradation	Yes	21.7 kg/m^2 40 lb/yd^2
4[(6)]	NB	AR (PG 70-10 Base Stock)	2.49 l/m^2 0.55 g/yd^2	12.5 mm ½ inch Coarser Gradation	Yes	21.7 kg/m^2 40 lb/yd^2
5[(7)]	NB	AR (PG 70-10 Base Stock)	2.49 l/m^2 0.55 g/yd^2	12.5 mm ½ inch Coarser Gradation	Yes	21.7 kg/m^2 40 lb/yd^2
6[(6)]	NB	AR (PG 70-10 Base Stock)	2.63 l/m^2 0.58 g/yd^2	12.5 mm ½ inch Coarser Gradation	Yes	14.7-21.7 kg/m^2 27-40 lb/yd^2
7[(1)]	NB	MB (PG 79-22)	1.90 l/m^2 0.42 g/yd^2	12.5 mm ½ inch	Yes	13.39 kg/m^2 30 lb/yd^2
8[(2)]	NB	MB (PG 73-22) TB	1.77 l/m^2 0.39g/yd^2	12.5 mm ½ inch	Yes[(8)]	16.27 kg/m^2 35 lb/yd^2
9[(3)]	NB	PMAR Field	2.40 l/m^2 0.53 g/yd^2	12.5 mm ½ inch	Yes	13.39 kg/m^2 30 lb/yd^2
10[(4)]	SB	MB (PG 86-16)	2.35 l/m^2 0.52 g/yd^2	12.5 mm ½ inch	Yes	16.27 kg/m^2 35 lb/yd^2
11[(5)]	SB	MB (PG 73-22)	1.99 l/m^2 0.44 g/yd^2	12.5 mm ½ inch	Yes	16.27 kg/m^2 35 lb/yd^2
12[(5)]	SB	MB (PG 73-22)	1.63 l/m^2 0.36 g/yd^2	9.5 mm 3/8 inch	Yes	13.39 kg/m^2 30 lb/yd^2

Notes for Table 1

(1) (8%CRM + 3% SBS, 100PAV) RAB field blend PG 76-22 (PG 79-22 actual)

(2) (5.5%CRM + 3% SBS, 110PAV) terminal blend PG 70-22 (PG 73-22 actual)

(3) (16%CRM + 2% SBS) PMAR field blend (Not PG Graded)

(4) (8%CRM + 3% SBS, 100PAV) RAB field blend PG 70-22 (PG 86-16 actual)

(5) (5.5%CRM + 3% SBS, 110PAV) terminal blend PG 70-22 (PG 73-22 actual)

(6) (22%CRM(17% scrap tire /5% high nat))+2% asphalt modifier +76% paving grade asphalt

(7) (22%CRM(17% scrap tire /5% high nat))+ 78% paving grade asphalt (PG 70-10)

(8) Last 25% of aggregate placed at north end of test section utilized uncoated aggregate

3. Phase 1 Studies-Asphalt Rubber Products

3.1 Construction

The purpose of the phase 1 test sections (1 through 6) was to evaluate the effects of the following factors:

- **Binder type**. The base stock asphalt used in the production of asphalt rubber binder is as follows; Test Sections 1 and 2 used AR 4000 for the base stock. Test Sections 3, 4 and 6 used a PG 70-10 base stock for the asphalt rubber binder. Test section 5 used the PG 70-10 base stock for the asphalt rubber binder without extender oil. The asphalt modifier was eliminated to determine if this would reduce or eliminate the flushing and bleeding experienced on prior projects.
- **Aggregate gradation.** The aggregate gradation of the chip seal was also a variable. In Test Section 1 (Control Section), the 12.5 mm (½ inch) max gradation used in prior projects was used. Test Sections 2 through 6 used a coarser more one size 12.5 mm (½ inch) max gradation in an attempt to minimize the flushing.
- **Binder application rate.** The previous asphalt rubber seal coat specification required that the binder application rate ranged from 2.48 to 2.94 l/m^2 (0.55 to 0.65 gal/yd^2). Test sections 1 through 3 utilized a lower application rate of 2.26 l/m^2 (0.50 gal/yd^2). A rate of 2.48 l/m^2 (0.55 gal/yd^2) was used on test sections 4 and 5 while test section 6 utilized an application rate of 2.27 l /m^2 (0.60 gal/yd^2).

- **Aggregate spread rates.** The aggregate spread rate specified and used in prior projects ranged between 14.7 to 21.7 kg/m^2 (27 to 40 lbs/yd^2). A target of 21.7 kg/m^2 (40 lbs/yd^2) was used for all test sections and the actual spread rates were between 20.6 to 21.6 kg/m^2 (38.0 to 39.9lbs/yd^2).

Construction of test sections 1-6 took place on May 12, 2005. The contractor, Manhole Adjusting Inc., supplied and placed both the asphalt rubber binder and the aggregate. The paving grade asphalt (AR4000) for test sections 1 and 2 was purchased from Paramount Petroleum. The paving grade asphalt (PG 70-10) for test sections 3 through 6 was purchased from Valero. The aggregate was supplied from Aggregate Products Inc. Salton Sea Beach. Upon completion of the chip seal, a flush coat was applied using a CSS-1 emulsion at an application rate of 0.36 l/m^2 (0.08 gal/yd^2) (diluted 1:1). The maximum air temperature during construction was 33.9^{o}C (93^{o}F). Details for the project can be found in the technical reports on this project [1][2] [3][4].

3.2 Performance Evaluations

After the initial construction of test sections 1 through 6, there was no loss of aggregate due to raveling or stripping on the chip seal. The performance of the test sections were evaluated several times after construction, 1 and 2 year surveys were conducted as a part of the Caltrans Asphalt Rubber Chip Seal (ARCS) study. The following pavement conditions were observed during the first survey which was performed after one year from the initial date of construction.

- **Bleeding/flushing**. The ARCS task force rated the pavements for the presence of flushing. They rated the pavements in terms of light, medium and heavy flushing. This can result in reduction in the coefficient of friction for pavements.
- **Streaking/Roping**. The task force also rated the pavements for the presence of lean longitudinal application rates of binder which results in aggregate loss in the lean bands.
- **Crack mitigation**. One of the main reasons to use ARCS is to mitigate cracks in the existing pavement from reflecting upward through the chip

seal. This was rated by the presence of reflection cracks through the chip seal.

Based on the review, it was considered by the task group that Test Section 3 rated the highest in terms of aesthetics, test section 4 rated the highest in terms of crack mitigation, and test section 5 had the most flushing.

Test sections 1 through 6 were rated again during a second survey preformed 2 years after the initial construction date. The test sections were also evaluated for flushing, rutting and skid resistance using both the California Test Method (CTM) 342 and the ASTM method E 274. All sections exceeded the minimum requirements for CTM 342, except test section 5 (most flushing) which failed to meet the minimum requirements. Based on this review, it was determined by the task force that Test Section 3 was again rated the highest in terms of aesthetics; test section 4 rated the highest in terms of crack mitigation and was the best overall. Test section 5 which was placed without asphalt modifier, exhibited heavy flushing and bleeding.

On November 3, 2010, several of the ARCS task force members conducted another survey to evaluate the condition of the test sections. Also evaluating the projects during this inspection were Dr. Gary Hicks of the CP2 Center and representatives of Paramount Petroleum. This was after five and one half years of heavy truck traffic and climatic loading.

Table 2 provides a summary of the test section evaluations. As it can be seen most of the sections are still performing, but with various signs of flushing. The best performance from the standpoint of flushing is still in test section 3 while the worst performance is in test section 5. The best performing section overall continues to be test section 4. Photos from these tests sections are shown in Figure 2.

Table 2. *Summary of Pavement Observations, November 3, 2010*

Section	Description	Current Condition
1	AR (AR-4000). Binder rate = 2.26 l/m^2 (0.50 gal/yd^2) Original aggregate gradation	Moderate Bleeding
2	AR (AR-4000). Binder rate = 2.26 l/m^2 (0.50 gal/yd^2). Coarse gradation.	Light to Moderate bleeding
3	AR (PG 70-10). Binder rate = 2.26 l/m^2 (0.50 gal/yd^2). Coarse gradation	Best overall combined performance in aesthetics and crack resistance
4	AR (PG 70-10). Binder rate = 2.49 l/m^2 (0.55 gal/yd^2). Coarse gradation	Moderate bleeding. Best performance overall due to crack resistance
5	AR (PG 70-10). Binder rate = 2.49 l/m^2 (0.55 gal/yd^2). No extender oil. Coarse gradation	2^{nd} Heaviest Bleeding
6	AR (PG 70-10). Binder rate = 2.63 l/m^2 (0.58 gal/yd^2). Coarse aggregate gradation.	Heaviest bleeding

a. Test Section 1 NB 86 AR 4000

b. Test Section 2 NB 86 AR 4000

c. Test Section 3 NB 86 PG 70-10

d. Test Section 4 NB 86 PG 70-10

e. Test Section 5 NB 86 PG 70-10 w/o asphalt modifier

f. Test Section 6 NB 86 PG 70-10

Figure 2. Photos of Phase 1 Test Sections 1 -6

4. Phase 2 Studies- Field and Terminal Blended Rubberized Asphalt

The construction of test sections 7 through 12 consisted of a combination of field blended and terminal blended products. The main purpose was to validate the Caltrans NSSP specification that was written without specifying a process, and which is based on end-result specifications used by Caltrans. Variations in aggregate size, with or without pre-coating, were included to check for construction variability and effect of aggregates on performance of the section based traffic loading. It should also be noted that the NSSP was changed after the test sections were constructed to require the use of PG 76-22 PM and PG 76-22 TR (min 10% CRM).

4.1 Binders

Several types of crumb rubber modified binders were used as a part of this study. The details of the binder usage are as follows:

- **Rubberized asphalt binder (RAB)**. This binder was field blended. The PG 70-22 (PG 79-22 Actual, 100 PAV) was used in the northbound #2 lane test section 7, while the PG 70-22 (PG 86-16 Actual, 100 PAV) was used in the southbound #2 lane test section 10. The asphalt base was a PG 70-10 supplied by Paramount Petroleum and was field blended by International Surfacing Systems (ISS), Inc., utilizing 8% CRM with 3% SBS polymer.
- **Terminal blend binder**. These products were supplied by Paramount Petroleum, utilizing 5.5% CRM with 3% SBS polymer. This binder was graded at PG 70-22 (PG 73-22 Actual, 110 PAV). Test section 8 was placed in the northbound #2 lane, while test sections 11 and 12 were placed in the southbound #2 lane. Test section 8, 11 and 12 all utilized the PG 73-22 Actual, 110 PAV binder.
- **Polymer modified asphalt rubber (PMAR)**. This product was used in the northbound #2 lane in test section 9. The asphalt base (PG 70-10) was supplied by Paramount Petroleum and was field blended by International Surfacing Systems (ISS), Inc., utilizing 16% CRM with 2% SBS polymer.

4.2 Aggregates

All aggregates used on test sections 7 through 12 were supplied from Coachella Valley Aggregates, Indio, Ca. The 9.5 mm (3/8 inch) chip was used only in test section 12, while the 12.5 mm (½ inch) chip was used in all other sections. All aggregates were pre-coated with a PG 70-10 binder at 1% binder content; except for the aggregate used in part of test section 8 used an uncoated aggregate.

4.3 Construction and Early Performance

The contractors for phase 2 were International Surfacing Systems (ISS) and Windsor Fuel. Windsor Fuel placed the terminal blends, while ISS placed the field blended RAB binders and the PMAR during October and November 2007. Significant aggregate loss occurred in test sections 7 through 12; however this subsided within 6 to 8 weeks after completion of the test sections. The amount of aggregate loss exhibited over the first 6 to 8 weeks after initial construction of test sections 7 through 12 is not acceptable to an owner, due to the excessive exposure to vehicle damage and public relations. The following exceptions were noted: test sections 7 and 8 exhibited excessive aggregate loss, bleeding or flushing; test section 9 never exhibited bleeding or flushing of any type; test sections 10 and 11 exhibited bleeding or flushing in the wheel paths occurred within a few months, but healed up by the end of the third year under the lighter southbound traffic loading; and test section 12 with the smaller 9.5 mm (3/8 inch) chip continued to bleed and flush even under the lighter traffic loading in the southbound direction. It should be noted that since the edges were not knifed, more raveling was experienced along the longitudinal joints for all of the test sections. When the temperature of the Paramount Petroleum terminally blended modified binder material dropped below 170^{o}C (340^{o}F) during application, the material became friable; which was concerning due to the liability for vehicle damage and public relations issues. However, there was no reported property damage during the placement of any of the test sections.

The weather during construction for the test sections was warm and clear. The average high temperature during construction was 27 to 34^{o}C (81 to 94^{o}F), with a surface temperature up to 46^{o}C (115^{o} F) while the lows at night were 11.1 to 13.9^{o}C (52 to 57 ^{o}F). The details of the construction can be found from the report of the project [5].

4.4 Performance Evaluations

Two site visits of these test sections were conducted for the phase 2 test sections 7 through 12. The first was in February 2010 and the second was completed in November 2010, over 3 years after construction.

4.4.1 Feb 2010 Evaluation

Test section 7 was constructed in the northbound direction, which has a heavier traffic loading using the ISS RAB field blended modified binder (PG 79-22 actual). This section exhibited early aggregate loss and moderate to heavy aggregate loss throughout the test section. The start of the section had less embedment of the aggregate (light flushing) than toward the end (moderate flushing). This test section demonstrated the second poorest performance of all the test sections (1 through 9) placed.

Test section 8 was constructed in the north bound direction, which has heavier traffic loading; using the Paramount Petroleum terminally blended modified binder (PG 73-22 actual). This section exhibited significant aggregate loss and heavy flushing. The aggregate loss and flushing was throughout the tests section. For test section 8, approximately 25% of the test section used uncoated aggregate. The uncoated material was at the end of test section 8 and the material carried over to test section 10, which did not exhibit the same aggregate loss. The aggregate loss cannot be attributed to the uncoated aggregate, as the aggregate loss was prevalent throughout the entire length of test section 8. The pre-coating of the aggregate has demonstrated the ability to provide for better adhesion between the aggregate and the binder, due to the paving grade asphalts incorporation with the heated aggregate. This process allows for a longer window for the seating of the aggregate during the chip seal placement operations; this emphasizes the requirement for aggregates to be pre-coated in the NSSP. This section demonstrated the poorest performance of all of the test sections 1 through 9 placed.

Test section 9 was constructed in the north bound direction, which has heavier traffic loading using the ISS polymer modified asphalt rubber (PMAR) binder. The test section was constructed to evaluate the performance of a material that is in the developmental stage (PMAR) binder and is currently being considered by the Caltrans binder committee. This section exhibited early aggregate loss similar to sections 7 to 12; however this material exhibited exceptional performance with regard to resistance to flushing (None). It is noted that test section 9 was placed in the northbound direction under heavy traffic loading and test sections 10 and 11 were placed in the southbound direction which is under lighter traffic loading. Test section 9 exhibited the best performance of all of the test sections 1 through 12, from an aesthetics point of view and performed well for crack mitigation when placed over a suitable pavement.

Test section 10 was constructed on the south bound under lighter traffic loading; using the ISS RAB field blended modified binder (PG 86-16 actual). Though this section exhibited early aggregate loss, it exhibited good performance in long term aggregate retention and in embedment and reflective cracking.

Test section 11 was constructed on the south bound lane under lighter traffic loading; using the Paramount Petroleum terminally blended modified binder (PG 73-22 actual). This section exhibited early aggregate loss and bleeding in the wheel paths during the first few years, but healed up by the third year.

Test section 12 was constructed on the south bound under lighter traffic loading; using the Paramount Petroleum terminally blended modified binder (PG 73-22 actual). In this test section, the aggregate was changed to a 9.5 mm (3/8 inch) pre-coated aggregates. This was done to evaluate the performance of the 12.5 mm (3/8 inch) compared to the 9.5mm (3/8 inch) aggregate. Under the same climatic and traffic loading the 12.5 mm (1/2 inch) aggregate clearly outperformed the 9.5mm (3/8 inch) aggregate. This section exhibited early aggregate loss and moderate to heavy flushing throughout the test section in the wheel paths. Based upon the observations and performance of test section 11 and 12, specification language was added to the standard special provisions (SSP) for asphalt rubber chip seals and the non-standard special provision for modified binders to only allow the uses of the 9.5mm (3/8inch) for interlayers. The 12.5mm (1/2 inch) medium aggregate gradations will be the primary aggregate utilized for chip seals for the State of California.

After a review of the PG grading of the supplied binders for the modified binder test sections, the NSSP specification was revised to include an upper limit on DSR in addition to the minimum value to ensure that the binders are not too stiff or too soft for the climatic region.

4.4.2 Nov 2010 Evaluation

The final survey was conducted in November 2010. As a reminder, Test sections 7 through 9 were placed in the northbound direction and had the heaviest traffic counts. Figure 3a, test section 7, shows the ISS RAB binder with a grading of (PG 79-22 Actual). It exhibited flushing in the wheel paths and significant aggregate loss throughout the test section. Figures 3b, test section 8, was the Paramount Petroleum terminally blended binder (PG 73-22 actual). It exhibited heavy flushing and aggregate loss throughout the entire test section. Test section 8 demonstrated the poorest performance of all of the test sections placed.

Figure 3c shows the condition of test section 9 which used the PMAR binder. This section had the highest CRM content of test sections 7 through 12 and the overall condition of the chip seal was excellent, with no flushing. Test section 9 performed the best of all of the test sections placed. Figure 3d shows the test section 10 RAB binder performed well under the southbound lighter traffic condition. Figure 3d shows the test section 11 12.5 mm (1/2 inch) aggregate with terminal blend with light flushing and Figure 3e shows the test section 12 with the 9.5 mm (3/8 inch) aggregate and terminal blend with significant flushing.

a. Test Sect. 7, **NB** RTE 86 ISS RAB Binder(**PG 79-22 actual**)

b. Test Sect. 8, **NB** RTE 86 Paramount Petroleum TB (**PG73-22 actual**)

c. Test Sect. 9, **NB** RTE 86 ISS PMAR using 16% CRM and 2% SBS polymer

d. Test Section 10, **SB** RTE 86 ISS RAB binder (**PG 86-16 actual**)

e. Test Sect. 11,SB RTE 86 Paramount Petroleum TB **(PG 73-22 actual**)

f. Test Section 12 SB RTE 86 Paramount Petroleum TB **(PG 73-22 actual**) with 9.5 mm (3/8 inch) gradation

Figure 3. *Photos of the Phase 2 test sections 7-12 during the November 2010 field visit*

Test section 9 did not mitigate reflection cracking as well as the asphalt rubber test sections 1 through 6, which is illustrated in Figure 4. However, when placed over sound pavement, the reflective crack mitigation was equal to or better than the modified binders (Paramount TB and the ISS RAB). This is primarily due to the higher application rate of the binder and the higher percentage of CRM which increased the viscosity of the binder and higher elastic properties of the PMAR binder.

Figure 4. *Test section 9 PMAR with some reflective cracking*

Figure 5 shows the condition of the test section 10 RAB PG 86-16 (actual) binder, which is in the southbound direction. The close-up of this section indicated good embedment and no flushing, under lighter traffic loading.

Figure 5. *Test Section 10, RAB binder PG 86-16 (actual)*

Test sections 11 and 12 were both the modified binders prepared by Paramount Petroleum at the terminal. The binder was prepared to meet a graded of PG 70-22, and the actual grade was (PG 73-22 actual). Test section 11 contained the 12.5 mm (½ inch) pre-coated aggregate while Test Section 12 contained the 9.5 mm (3/8 inch) pre-coated aggregate. As can be seen in Figure 6 there was aggregate loss that occurred shortly after construction for 4 to 6 weeks. The aggregate loss on the edge is due to not knifing the edge and a plugged tip.

Figure 6. *Test Section 11 showing aggregate loss*

Figure 7 shows the condition of the only test section that used 9.5 mm (3/8 inch) chip aggregate. This test section had the most bleeding, but not as much aggregate loss as test section 11. It is clear the 9.5 mm (3/8 inch) aggregate is not appropriate for chip seals in these types of conditions. This aggregate size has been used successfully in other parts of the state with more moderate temperatures and traffic conditions. The aggregate loss on the edge is due to not knifing the edge and a plugged tip.

Figure 7. *Test section 12, Close-up of PG 73-22 with 9.5 mm (3/8 inch) aggregate*

A summary of the overall condition of the various modified binder test sections for the November 2010 visit is given in Table 3.

Table 3. *Summary of Pavement Condition for the Modified Binder Test Sections after 3 years*

Test Sect.	**Date: October-November 2007--- Constructed Phase 2**		**Wheel Tracking Flushing**		**Pavement Condition Evaluation**
			Light	**Moderate**	
7	RAB, PG 70-22 (PG 79-22 actual) base	12.5 mm ½ inch		X	Moderate To Heavy bleeding w/aggregate loss
8	PG 70-22 (PG 73-22 actual) w/rubber TB	12.5 mm ½ inch		X	Heavy aggregate loss/ stripping and bleeding
9	PMAR Field Blend	12.5 mm ½ inch	None		No bleeding but some reflection cracking
10	RAB, PG 86-16 (actual) base	12.5 mm ½ inch	None		Section is performing well
11	PG 70-22 TR (PG 73-22 TR actual)	12.5 mm ½ inch	X		Edge aggregate loss (early), not much bleeding
12	PG 70-22 TR (PG 73-22 TR actual)	9.5 mm 3/8 inch		X	Moderate aggregate loss in non-wheel path area/ bleeding in wheel paths.

5. Conclusions and Recommendations

The findings of these chip seal studies after 3 and 5 years of performance under extremely high ambient and pavement temperatures, in addition to heavy traffic loading in the northbound direction are as follows:

- Phase 1 study resulted in a number of conclusions to mitigate flushing and bleeding in ARCS throughout the State of California and specifically in the desert climate of District 11.
  - The findings from the study suggested; that using a stiffer PG graded base stock asphalts are beneficial in the production of asphalt rubber binder, a coarser more one size 12.5mm (1/2 inch) aggregate gradation and lower binder application rates in the wheel paths can mitigate flushing. . The use of the stiffer PG graded base stock asphalt has a detrimental impact in preventing reflective crack mitigation.
  - The recommendations of the study are applicable to very hot climates and where the ARCS are subjected to heavy traffic. However, some of the recommendations may also be applicable to the different climatic zones and the various traffic loadings in California.
  - Reducing the application rate in the wheel paths through the use of a variable rate spreader bar can also help reduce the amount of flushing and bleeding in the wheel paths. The use of the variable rate spreader bar also allows for the application rate to be higher in the non-wheel path which helps mitigate aggregate loss outside of the wheel paths.
- The Phase 2 study resulted in the following conclusion:
  - The modified binders placed in test section 7, 8, 10, 11 and 12, exhibited aggregate loss during the first 4 to 6 weeks after construction. This exposure to vehicle liability and public relations is not considered acceptable.
  - Test sections 7 and 8 exhibited varying degrees of flushing from light to heavy and aggregate loss from light to heavy. Test section 8 exhibited the poorest performance with heavy aggregate loss and flushing throughout the test section. The distress exhibited in these test sections would not be acceptable and would be deemed a failure when subjected to this climate and traffic loading.

- Test section 9 preformed the best of all of the test sections placed under phase 2. This section exhibited excellent performance, aesthetically the chip seal had no flushing at all throughout the entire length of the test section. The crack mitigation properties were excellent when placed over suitable existing pavement.
- Test sections 10 and 11 performed well under the same climatic condition, but under a lighter traffic loading. However, early aggregate retention is a serious concern and needs to be addressed.
- Field and terminal blend modified binders had very similar performance rated as unacceptable in test sections 7 and 8 placed the northbound direction (heavy traffic) and acceptable in test sections 10 and11 placed in the southbound direction (lighter traffic) even with the differences in the actual PG grading of the binder.
- The binder application rate is important across the pavement with similar distress levels to achieve good results. Excess binder in the wheel tracks will lead to flushing.
- Calibration and verification of application rates are essential to obtaining a quality chip seal. Though everyone knows this to be true, it is not always checked.
- It is clear that the modified binders caused a problem with aggregate retention early in the life of the modified binder chip seal. This was evident in the aggregate loss during the first 4 to 6 weeks of the chip seal performance, but the products are still performing in the southbound direction.
- For chip seal applications, an upper appropriate stiffness is needed to mitigate reflective cracking and embedment level, so maximum and minimum DSR’s have been set in the NSSP. The stiffer binders are not expected to perform as well to mitigate reflection cracking.
- Hot pre-coated aggregates enhance the performance of the chip seal. The hot pre-coated aggregates promote a better bonding and aggregate retention throughout the life of the seal coat.

  - The 12.5 mm (½ inch) medium one size pre-coated chip is needed in hot climates for the best performance under heavy traffic. The 9.5mm (3/8 inch) chip did not perform well and exhibited moderate to heavy wheel path flushing in test section 12. For hot applied chip seals in California it is recommended that the minimum aggregate gradation be 12.5mm (1/2 inch) medium. The 9.5mm (3/8 inch) aggregate gradation is only recommended for interlayer's.
  - QC/QA testing frequencies have been included in the NSSP to insure materials such as the binders and aggregates materials are in compliance with the specification.
  - Lack of binder in the non-wheel path led to raveling of the aggregate, while too much binder in the wheel path led to the flushing/bleeding. The use of a variable rate spreader bar is a solution when the chip seal is under heavy traffic loading as the rate can be varied between the wheel path and the non-wheel path, in order to mitigate the flushing in the wheel paths and the aggregate loss in the non-wheel path.

- An overall evaluation of test sections 1 through 9 placed in the northbound direction under the same traffic and climatic loading yielded the following conclusions:
  - Aesthetics are by far the overriding factor when evaluating the success of a chip seal. Crack mitigation performance also factors into the performance equation.
  - Test section 9 PMAR preformed the best overall with regard to combined aesthetics, and crack mitigation.
  - The asphalt rubber test sections 1 through 6 outperformed the modified binder test sections 7 and 8, with regard to aggregate retention, flushing, crack mitigation and aesthetics.
  - The asphalt rubber test sections 1 through 6 outperformed the PMAR test section 9 PMAR with regard to crack mitigation. This is primarily due to the higher application rate of the asphalt rubber binder and the higher elasticity of the asphalt rubber

binder. The crack mitigation properties of the asphalt rubber test sections were affected by the lower application rates and base stock PG grade asphalt used in the various test sections.

- It is essential that the spreader bar be calibrated and verified prior to placement of binder in order to place the correct binder application rate both in the wheel path and the non-wheel path areas of the pavement. This will prevent flushing in the wheel path area and loss of aggregate in the non-wheel path areas.
- The use of a variable rate spreader bar for binder application has proven to be successful in placement of asphalt rubber chip seals subjected to the same climate and higher truck traffic loading conditions. This yielded a similar aesthetic result to the PMAR test section with superior crack mitigation abilities.

6. Bibliography

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