WHITE PAPER

COMPARISONS OF RUBBERIZED ASPHALT BINDERS
Asphalt-Rubber and Terminal Blend

for the

RUBBER PAVEMENTS ASSOCIATION

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INTRODUCTION

This white paper discusses the two processes used to incorporate recycled tire rubber in hot mix asphalt and seal coats. These two processes are distinct and produce two completely different binders, namely; Asphalt-Rubber and Terminal Blend (Figures 1 and 2). Each of these binders has its own properties and unique applications.

Figure 1. Asphalt-Rubber Binder

Figure 2. Terminal Blend Binder

Asphalt-Rubber

Asphalt-Rubber (Figure 1) has been successfully utilized for over 35 years and is historically known as the “wet process” and is a public domain process defined by ASTM as: “A blend of asphalt binder, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt binder sufficiently to cause swelling of the rubber particles.” [2]

The application of crumb rubber modifier (CRM) in asphalt mixtures is intended to improve the properties of binder by reducing the binder’s inherent temperature susceptibility. During the interaction with asphalt binder, the CRM particles in asphalt-rubber absorb a portion of the oils in asphalt binder and the particles swell; therefore increasing the viscosity and stiffness of the CRM binder. This does not occur in Terminal Blend binders.

The addition of rubber into the asphalt binder increases the elasticity and resilience of the binder. It improves the durability and resistance to fatigue and reflective cracking in hot mixes and chip seal applications. Also, it enhances the chip retention in chip seals.

There are two types of asphalt-rubber binder; Type I and II. Type I is mainly used in Arizona and Texas. It contains asphalt binder and 18 to 20 percent tire rubber that meet a specific gradation requirement. Type II is used in California and consists of about 20 percent rubber (75 percent ground tire rubber with a suitable grading, and 25 percent natural rubber, also with a suitable grading.). In addition heavy aromatic oils (asphalt modifier) may be added up to 6 percent. Type I and Type II binders are used internationally. The asphalt-rubber binder is blended using a low shear system for a minimum of 45 minutes. [3]

<u>Terminal Blend (Modified Binder or PG 70-22TR and PG 76-22TR)</u>

The Terminal Blend binder is a patented, proprietary rubberized asphalt binder that utilizes a fine mesh of crumb rubber blended in the refinery or stationary asphalt terminal with asphalt binder and the component materials are heated over an extended period of time. This results in dissolving of the rubber particles (Figure 2). The amount of rubber used in this process may vary anywhere between 5 to 20 percent. It is important to note that an independent test verification of actual rubber percentage has not been developed to date. This binder is manufactured similar to polymer modified asphalt. Recently the specifications used for Terminal Blend have utilized the PG grading system similar to the ones used for polymer modified asphalt (Table 1). [1]

GENERAL COMPARISONS

Asphalt-Rubber and Terminal Blend are distinctly different binders. Both have shown improvements over conventional binders but based on the case studies and laboratory tests cited, Asphalt-Rubber exceeds Terminal Blends in terms of its performance. Asphalt-Rubber has more performance history since this process started over 35 years ago.

There are uses for each binder. When it comes to hot mixes, one of the best uses for Terminal Blends is in DGAC whereas Asphalt-Rubber is best utilized in RAC-G and RAC-O. This is because the gap gradation and open gradation allow space for the Asphalt-Rubber particles. Asphalt-Rubber should not be used in dense graded mixes since the rubber particles can create a compaction problem because the space requirements for the particles are not there. Moreover, the lower viscosity of Terminal Blends results in lower optimum binder contents in hot mixes that translate into less performance life.

Surface chip seals and interlayers have been performing successfully using Asphalt-Rubber. Terminal Blends' history in this area has not been long enough to provide a comprehensive understanding of its performance. However, the lower viscosity of Terminal Blend binders results in lower application rates than if the higher viscosity of Asphalt-Rubber binder is used. The lower application rates mean less binder per unit area indicating less performance life than if Asphalt-Rubber is used. The ability to inject more binder in the mix translates to better fatigue and reflective cracking performance.

Table 1. Performance Graded Tire Rubber Modified Asphalt Binder [a]

Property	Test Method	Specification Grade		
			PG 64-28 TR	PG 76-22 TR
Original Binder				
Flash Point, Minimum °C	D 92		230	230
Solubility, % minimum	D 5546 or D 2042[b]		97.5	97.5
Viscosity at 135°C, [c] Maximum, Pa·s	D 4402		 3.0	 3.0
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	D 7175		 64 1.00	 76 1.00
RTFO Test , Mass Loss, Maximum, %	D 2872		 1.00	 1.00
RTFO Test Aged Binder				
Dynamic Shear, Test Temp. at 10 rad/s, °C Minimum G*/sin(delta), kPa	D 7175		 64 2.20	 76 2.20
Elastic Recovery, Test Temp., °C Minimum recovery, %	D 6084 Method B		 25 75	 25 65
PAV[e] Aging, Temperature, °C	D 6521		 100	 100 (110)[d]
RTFO Test and PAV Aged Binder				
Dynamic Shear, Test Temp. at 10 rad/s, °C Maximum G*sin(delta), kPa	D 7175		 22 5000	 31 5000
Creep Stiffness, Test Temperature, °C Maximum S-value, MPa Minimum M-value	D 6648		 -18 300 0.300	 -12 300 0.300

Notes:

a. PG-TR grades require a minimum of 10 percent by weight ground tire rubber content.
b. D 5546 is allowed as an alternate test to D 2042
c. This specification may be waived if the supplier certifies the asphalt binder can be adequately pumped and mixed at temperatures meeting applicable safety standards.
d. In desert climates, the PAV aging temperature may be specified as 110 °C
e. "PAV" means Pressurized Aging Vessel.

It should be mentioned that both binders (Asphalt-Rubber and Terminal Blend) will still perform better than if only a conventional asphalt binder is used. It is important to consider key factors affecting performance such as binder properties and binder contents or application rates. Combining these factors together produces a positive compounding effect on the performance.

STRATEGIES

Terminal Blend binders have been utilized on a limited basis in chip seals and hot mix dense graded applications. Asphalt-Rubber binders have been used in various strategies including the following:

- Chip seals
- Interlayers

- Hot mix-open graded
- Hot mix-open graded high binder
- Hot mix-gap graded
- Hot mix-dense graded

The above referenced applications have been utilized by public agencies in construction and maintenance work and have been reported upon by researchers using different acronyms that refer to the same application or process utilizing Asphalt-Rubber binder.

For clarification and to avoid any confusion, Table 2 provides side by side comparisons for some commonly used acronyms concerning Asphalt-Rubber systems.

Table 2. Common Acronyms

Strategy	**Arizona**	**Current Caltrans**	**Green Book* and Others**	**Previous Caltrans**
Chip Seals	SAM	ARSC	ARAM*	
Interlayers	SAMI	SAMI-R	ARAMI*	
Open Graded		RHMA-O	ARHM-OG	RAC-O
Open Graded-High Binder	ARFC	RHMA-O-HB		
Gap Graded	ARAC	RHMA-G	ARHM-GG*	RAC-G
Dense Graded		RHMA-D	ARHM-DG	RAC-D

* Strategies used in the *"Standard Specifications for Public Works Construction" – The "Greenbook"*.

As shown in Table 2, Asphalt-Rubber chip seals can be referred to as SAM, ARSC or ARAM which stand for stress absorbing membrane, Asphalt-Rubber seal coat or Asphalt-Rubber Aggregate Membrane, respectively. Interlayers are referred to as SAMI in Arizona, and SAMI-R or ARAMI in California, denoting stress absorbing membrane interlayer ("R" for rubber) or Asphalt-Rubber aggregate membrane interlayer, which are the same application process. Open graded mixes can be referred to as Asphalt-Rubber friction course (ARFC), and RHMA-O or ARHM-OG denoting rubberized hot mix asphalt with "O" or "OG" for open graded, or RAC-O denoting rubberized asphalt concrete. Gap graded mixes can be referred to as Asphalt-Rubber asphalt concrete (ARAC) in Arizona, and RHMA-G, ARHM-GG or RAC-G in California. All of these terms have one commonality; they all use Asphalt-Rubber binder.

Asphalt-Rubber binder has been used on all of the above strategies. These strategies have been used successfully on many projects. However, Asphalt-Rubber is not recommended for use on dense graded hot mix projects since the dense gradation cannot adequately accommodate the rubber particle size. On the other hand, Terminal Blend binders are most suitable for dense graded mixes. Terminal Blends have been used on limited or experimental basis for chips seal applications, and in open graded and gap graded mixes.

HISTORICAL PERSPECTIVE

Several pioneering states including Arizona, California, Texas and Florida, and some countries have been using recycled tire rubber in Asphalt-Rubber chip seal applications since the early 1970s, and in hot mix applications since the mid 1980s. Early trials included the use of both the Asphalt-Rubber wet process and the dry process of incorporating recycled rubber; however most of the work completed in the 1990s and in this decade has employed the Asphalt-Rubber wet process. As a result of all of these many trials, test sections and research activities specifications and practices have improved and construction procedures have been refined to provide consistently good performance.

There have been many efforts and investigations on Asphalt-Rubber products. Below is a list of some of these activities.

- 1999 - 2003: Heavy Vehicle Simulation on several field constructed overlay test sections
- 1997 - 2003: 10 pilot projects using modified binder and 5 using warranty specifications
- 2004 - 2005: Two field full scale experiments (total 13 test sections)
- 2005: Field projects (rubberized bonded wearing course)
- Quieter pavements using open-graded high binder (HB)
- Recycling of HMA containing Asphalt-Rubber
- Full-Depth Recycling (FDR) of projects containing Asphalt-Rubber chip seals or interlayers
- Use of Asphalt-Rubber in warm mix asphalt

Additionally, field condition surveys of Asphalt-Rubber projects were conducted in California on over 100 projects in 1995 and on over 210 projects in 2001 that showed superior field performance over conventional strategies.

A 2005 Assembly Bill (AB338) in California called for progressive amount of usage of tire rubber in paving materials over several years. The Bill mandates increased usage of rubber in paving materials from 20 percent in 2007 to 35 percent in 2013. By 2010, Caltrans reached an amount of over 30 percent of the total hot mix asphalt projects.

The growing demand for Asphalt-Rubber technology requires the use of effective specifications and guidelines to ensure its continued successful performance. Some of this technical guidance is included in the following:

- 1992 Reduced Thickness Guidelines (for Asphalt-Rubber) [3]
- 2002 Asphalt-Rubber Usage Guide (for Asphalt-Rubber) [4]
- 2003 Maintenance Technical Advisory Guide (MTAG) (for Asphalt-Rubber and Terminal Blend) [4]
- 2006 Updated Asphalt-Rubber Usage Guide (for Asphalt-Rubber and Terminal Blend) [4]
- 2007 MTAG 2nd Edition (for Asphalt-Rubber and Terminal Blend) [4]

CASE STUDIES

Direct performance comparisons between Asphalt-Rubber and Terminal Blend have been limited due to the short history of Terminal Blends, and since the Terminal Blend technology has been evolving over the years. Below are several case studies that have investigated the two binders.

ALF Test Sections:
A pooled fund study was conducted in 2002 at Turner-Fairbank Highway Research Center in McLean, Virginia, where twelve lanes of HMA were constructed with various modified asphalts. Two of the test lanes used crumb rubber material technology. Lane 1 employed the Arizona wet process (CR-AZ) and Lane 5 employed the Texas Terminal Blend process (CR-TB). Lane 2 was constructed with an unmodified asphalt binder as the control section. Other lanes included air-blown, polymer and fiber modified asphalt binders. These materials underwent accelerated pavement testing using the Accelerated Pavement Facility (ALF) machine at 19º C as well as laboratory performance tests. See Figure 3. The results showed that the CR-AZ test performed the best in terms of fatigue and reflective cracking. Cores taken from Lane 1 indicated that the bottom lift (control mix) had cracked after 300,000 loading applications but those cracks did not reflect through the CR-AZ. All other sections cracked much earlier. This important finding validates previous studies showing the superior reflective cracking performance of Asphalt-Rubber mixes.

The CR-TB showed better fatigue cracking resistance than the control Lane 2 and Lane 3 with air-blown asphalt but worse than other types of modified binder lanes. ALF rutting at 64º C showed CR-TB as having the lowest rut resistance while the CR-AZ showed similar rut resistance as the rest of the sections. [5]

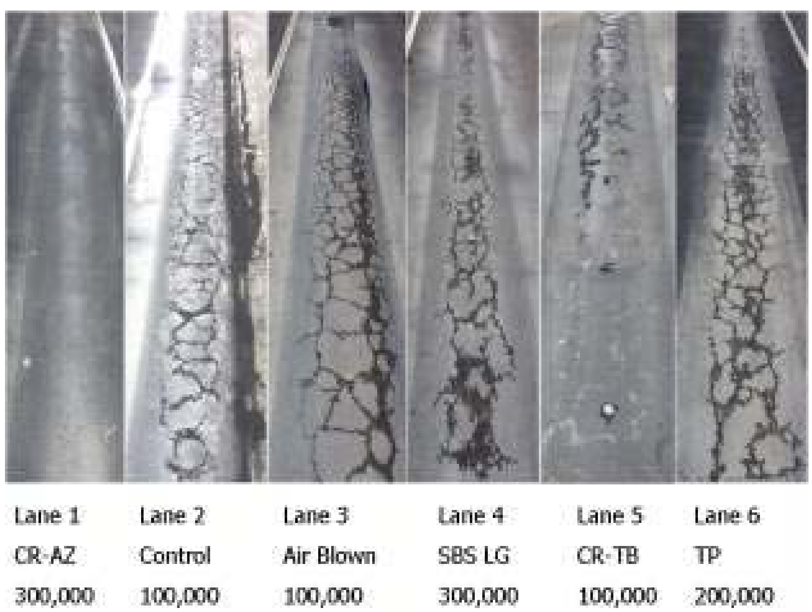

Figure 3. Distress of ALF Test Sections

HVS Test Sections
Recent Heavy Vehicle Simulator (HVS) tests were conducted to evaluate the performance of several rubberized HMA mixes in 2001 at the University of California Richmond Field Station. [6] The following mixes were used in the evaluation: 1) MB4-G: Terminal Blend gap graded mix with 5 percent ground tire rubber, 2) MB4-15-G:Terminal Blend gap graded mix with 15 percent minimum ground tire rubber, 3) MAC-15TR-G:Terminal Blend gap graded mix with 15 percent minimum ground tire rubber, 4) RAC-G: Asphalt-Rubber hot

mix gap graded mix, and 5) AR 4000-D: dense graded asphalt concrete mix. The rubberized sections were placed at 45 mm while the DGAC sections were placed at 90 mm thickness.

The reflective cracking performance for each of the overlays was reported to be the best for the Terminal Blend mixes followed by the Asphalt-Rubber section. The dense graded HMA showed the poorest performance. These results were similar to the laboratory beam fatigue tests in terms of their relative ranking. The rutting performance results showed the conventional DGAC test section to be superior over the other sections followed by the Asphalt-Rubber and Terminal Blend sections. The remaining Terminal Blend sections showed the poorest rutting resistance. The results from this study contradict the results from the ALF study. This may be due to the higher binder content of the Terminal Blends used in the HVS study of roughly 7.6 percent by weight of aggregate as compared to the binder content of the Terminal Blend which was 5.6 percent by weight of aggregate in the ALF study. The higher binder content in the Terminal Blend can be the contributing factor to the poor rutting performance in some of the Terminal Blend sections.

Firebaugh Test Sections

Caltrans constructed 9 test sections in June 2004 consisting of a dense graded asphalt concrete (DGAC), a rubberized asphalt concrete-gap graded (RAC-G, wet process), a rubber modified asphalt concrete (RUMAC-GG, dry process), two Terminal Blend processes containing a minimum 15 percent CRM, a Type G modified binder (MB-G) and a Type D modified binder (MB-D). [7]

Based on the laboratory testing of these mixes the authors concluded the following: 1) The RAC-G and RUMAC-GG mixes were generally the most rut resistant and the DGAC were the least resistant in the Superpave Shear Test (SST), 2) the MB-G mix was the most fatigue resistant and the MB-D and DGAC mixes were the least resistant in the flexural fatigue beam test, and 3) the RUMAC-GG mix had the best overall performance in the Hamburg wheel tracking test while the MB-D and MB-G were the poorest performers. The optimum binder contents for the various mixes were 7.9 percent, 7.9 percent, 6.3 percent, 5.3 percent, and 4.8 percent for RAC-G, RUMAC-GG, MB-G, MB-D, and DGAC, respectively. The air voids were 7.1 percent for RAC-G, 4.7 percent for RUMAC-GG, 1.9 percent and 3.7 percent for MB-G, 3.9 percent and 3.6 percent for MB-D, and 6.8 percent for DGAC. It is well known that fatigue is significantly influenced by air voids. Since the effect of air voids on fatigue performance is well documented, the large discrepancy in air voids puts the conclusions of this study in doubt. For example, if one holds all other variables constant except the air voids, and uses The Asphalt Institute fatigue model, the fatigue life can be as much as 11 times more for the MB-G mix with air void levels of 1.9 percent and 2.7 percent as compared with the RAC-G mix at an air void level of 7.1 percent.

Chip Seals (SAM or ARAM) and Stress Absorbing Membrane Interlayers (SAMI-R or ARAMI)

The performance of Asphalt-Rubber chip seals has been good. Caltrans placed 6 chip seal test sections in Imperial County, California with various specification requirements. See Figure 4. These tests have already resulted in significant improvements in the specifications.

Figure 4. Chip Seal

Rubberized stress absorbing membrane interlayers using Asphalt-Rubber (SAMI-R) have been widely used in rehabilitation applications. SAMIs are used to retard reflective cracking, prevent water intrusion and in the case of SAMI-R enhance the pavement structural value.

In 1993, Caltrans constructed 11 test sections on Route 116 near Esparto, California consisting of various pavement preservation strategies that included Asphalt-Rubber chip seal, RAC-O, RAC-G, DGAC, RAC-G with SAMI, RAC-O with SAMI and DGAC with SAMI. The performance after 10 years showed that the Asphalt-Rubber sections performed significantly better than the sections with conventional mixes. In addition, the sections with SAMI performed better than the sections without a SAMI. Additionally, the RAC-O with a SAMI showed the best performance when compared with the same mixes without a SAMI. [3]

The successful performance of these applications led Caltrans into developing reflective cracking equivalencies for these applications. For example, when RAC-G is used as an overlay, SAMI-R (ARAMI) is considered to have reflective cracking equivalencies of 15 mm and 30 mm for treated and untreated bases, respectively. Also, the reflective cracking equivalencies are 30 mm and 45 mm when a conventional DGAC overlay is used for treated and untreated bases, respectively. [9], [10] Additionally, the Caltrans MTAG shows Asphalt-Rubber chip seal as the only single application chip seal recommended for control of load associated cracks and climate associated cracks. [4]

MATERIAL PROPERTIES AND KEY SPECIFICATION PARAMETERS

The performance of rubber-modified binders depends on the elastomeric properties which are influenced by the manufacturing process. It is important to achieve the required level of digestion of the rubber in the binder through adequate dispersion to create a rubber-network or matrix within the asphalt binder. The physical aspect of mixing creates a physio-chemical interaction between the asphalt and the rubber. [3]

It is difficult to compare the material properties of Asphalt-Rubber and Terminal Blend binders since the Terminal Blend process has been a moving target in terms of the amount of rubber added to the binder. Performance specifications have been used that can be met with either a polymer modified asphalt or a combination of CRM and polymer to modified asphalt binder. These specifications include a solubility requirement of 97.5 percent. Table 1 shows performance specifications for Terminal Blend binders. It should be mentioned here that these properties may also be met with polymer modified asphalt.

The viscosity for Terminal Blend binders can range between 500-1000 centipoises at 275ºF, lower than the viscosity for Asphalt-Rubber which is in the range of 1500-4000 centipoises at 375ºF (Table 3). This results in lower binder content for hot mixes and in lower application rates for chip seals. It is important to note that the viscosity for the Terminal Blend is measured at 275ºF while the viscosity for Asphalt-Rubber is measured at 375ºF. For a better comparison, laboratory tests were conducted on both binders at 375ºF. These results showed a viscosity of 75 centipoises for the Terminal Blend which is on the average over 36 times less than the viscosity for Asphalt-Rubber. This is a very significant difference.

The high viscosity of the Asphalt-Rubber binder allows for increased binder contents in paving applications. In hot mix, binder contents between 8-10 percent are common and in chip seals, an application rate around 0.55-0.65 gallon/sq.yd. is commonly used. Terminal Blends have lower optimum binder content in the range of 5-6 percent for dense graded mixes, and lower application rates around 0.25-0.50 gal/sq. yd. for chip seals depending on the aggregate size. Terminal Blend chip seal commonly uses a 3/8 inch maximum aggregate size and requires an application rate in the 0.30-0.42 gal/sq. yd. range, while Asphalt-Rubber chip seal generally uses a 3/8 to 1/2 inch aggregate size with a 0.55-0.65 gal/sq. yd. application rate.

Few investigators have conducted studies on the properties of these binders. For example, Thodesen, et. al. evaluated several binders using the multiple creep recovery test. [6] Among the binders studied were an Asphalt-Rubber binder and a Terminal Blend binder that uses 10 percent CRM and 1 percent SBS polymer. The Asphalt-Rubber binder was in accordance with the Arizona specifications. The results showed that the Asphalt-Rubber binder exhibited the least creep and the highest percent recoveries under various loading and temperature ranges (Figures 5 and 6). The Terminal Blend binder yielded high percent recoveries, however, it was seen that at the higher loading rate it did not recover as much as the Asphalt-Rubber. For illustration, Figure 5 shows the percent recovery at 100 and 3200 Pa at a temperature of 70ºC. As can be seen, Asphalt-Rubber exhibited over 160 percent recovery and the Terminal Blend showed over 100 percent recovery at the 100 Pa shear stress level. Similar trends are shown at the 3200 Pa shear stress level.

DISCUSSION

The need to react, or swell the CRM in asphalt binders has been widely accepted and specifications have included a minimum reaction time for Asphalt-Rubber. It has been thought that the Asphalt-Rubber particles would swell during the reaction time by absorbing the maltene which acts as release capsules over time resulting in enhanced aging properties for the Asphalt-Rubber binder. On the other hand, the Terminal Blend binders are made by heating the binder for an extended period at high temperatures that result in dissolving the rubber particles.

Table 3. Asphalt-Rubber Binder Properties over Time in a Binder Design Profile

Test Performed	Minutes of Reaction					Specified Limits
	60	90	240	360	1440	
Viscosity, Haake at 177°C, Pa-s	2.7	2.8	2.8	2.8	2.0	1.5-4.0
Centipoise cP	2700	2800	2800	2800	2000	1500-4000
Resilience at 25°C, % Rebound (ASTM D3407)	34		36		32	30 Min.
Ring & Ball Softening Point, °F (ASTM D36)	150	150.5	152.5	154.5	145	135 Min.
Needle Penetration at 4°C, 200g, 60 sec., 1/10mm (ASTM D5)	22		24		26	10 Min.

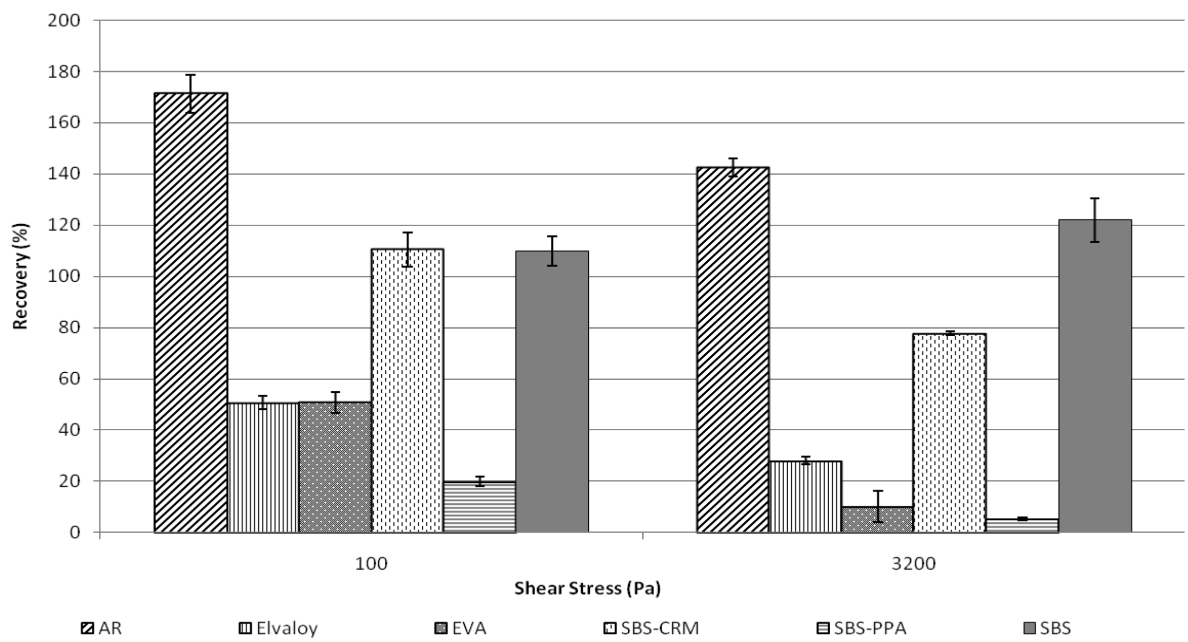

Figure 5. Percent recovery at 100 and 3200 Pa at 70º C [6]

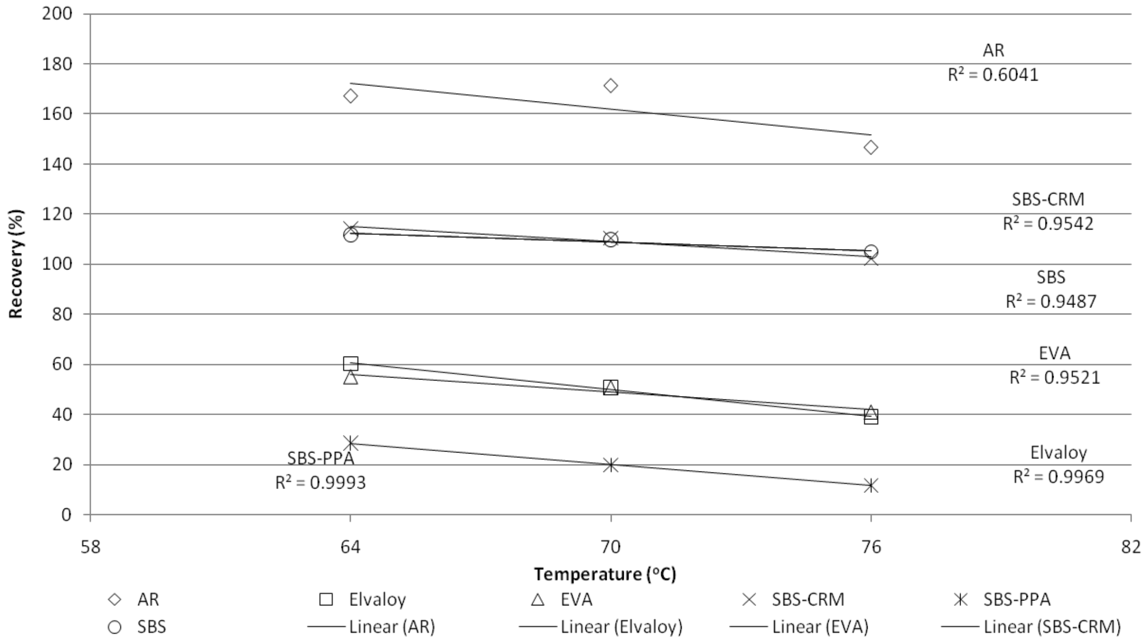

Figure 6. Percent recovery versus temperature [6]

Terminal Blend technology has been evolving. The effect of heating the binder over time has not been clearly understood yet. The questions that remain to be answered include; 1) Do the binder properties degrade as a result of the extended heating over time, 2) Does the melting of the rubber particles enhance the properties and performance of the binder, 3) How well can the amount of rubber be determined in the binder, 4) How important is the solubility requirement in the specifications.

CONCLUSIONS

It can be concluded that Asphalt-Rubber and Terminal Blend are distinctly different binders. The two binders are not equal or equivalent materials. The following are the highlights of some of these differences:

- Performance tests showed Asphalt-Rubber to have better performance than Terminal Blend.
- Asphalt-Rubber chip seal is the only single application chip seal recommended for control of load associated cracks and climate associated cracks per the Caltrans Maintenance and Advisory Guide (MTAG).
- The two binders have completely distinct specification requirements. Asphalt-Rubber has a long established and consistent specification utilizing the same ingredient components. Terminal Blend specifications continue to evolve and change with little laboratory or field data to determine the effect of such changes.
- The Terminal Blend specifications can be met with a polymer modified binder.
- The viscosity of Terminal Blend averages over 36 times lower than the viscosity of Asphalt-Rubber resulting in much lower application rates and binder contents which

translate into less fatigue and reflective cracking resistance. Higher viscosity in Asphalt-Rubber relates to greater film thickness which provides extended service life performance.

- The rubber in the Asphalt-Rubber binder does not degrade through the curing process, opposed to Terminal-Blends, where rubber is completely dissolved.
- Fully digested rubber in a binder (Terminal Blend) does not provide for substantial resistance to load and climatic cracking when compared with an Asphalt-Rubber chip seal.
- Asphalt rubber binder should not be used in dense graded mixes where Terminal Blend is best utilized.
- Asphalt rubber has shown a long performance history in chip seals, interlayers and gap graded mixes. Terminal Blend is new, and a currently experimental product with a limited performance history concerning chip seals, interlayers, and gap grade mixes.
- Both binders provide improvements over strategies that use conventional asphalt cement.

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