Caltrans use of rubberized asphalt concrete (RAC) spans nearly three decades. In the 1970s, RAC was used in dense-graded asphalt concrete mixes on an experimental basis. The RAC layer thickness was designed equal to that of conventional dense-graded asphalt concrete (DGAC). The mix design procedures and construction practices used were developed by material suppliers but were not well documented.

In the 1980s, an experimental project (Ravendale Project) included both RAC and DGAC overlays of several thicknesses. Performance monitoring led Caltrans staff to conclude that a thickness reduction for RAC mixes was appropriate. Subsequently, several Caltrans Districts placed both dense- and open-graded RAC mixes though there is little documentation as to mix design and performance data.

In the 1990s, Caltrans continued to study rubber modified mixes through full-scale accelerated testing and field projects. The South African Heavy Vehicle Simulator (HVS) was used to evaluate rubber modified gap-graded mixes as well as conventional dense-graded mixes. The results of the study confirmed that gap-graded mixes of reduced thickness mitigated reflection cracking. Additional studies at the University of California Berkeley confirmed this finding.

Over 100 field projects, both rehabilitation and maintenance, were constructed throughout the state by the mid 1990s. Two types of binders (Type I and Type II) were also used. A field review of these projects in 1995 indicated that thin rubber overlays generally provided good performance when properly designed and constructed and that Type II binders performed better than Type I binders. In a follow-up visual assessment survey in 1999 on projects constructed since 1995, a Caltrans-Industry team rated 90% of the projects as “good” and the remaining 10% as “fair” or “poor”.

Other asphalt rubber hot mix projects placed during the 1990s included one at Newberry Springs (I-40), a warranty project on Interstate-5 in District 2, a rehabilitation project on Interstate-10 in Riverside County, a project on State Route 101 in District 5, and an experimental project on State Route 16 in Yolo County. The performance of these pavements varied by project.

Another study undertaken in the 1990s was the use of a modified binder (MB) containing both crumb rubber and a polymer modifier that could be manufactured at a terminal facility. Ten pilot projects were constructed to evaluate the performance of materials meeting the MB specification. These projects were reviewed by a Caltrans-Industry group in 2002. Eight projects were rated as “good,” and one each was rated as “fair” or “poor.”

RAC studies conducted in the early 2000s included an evaluation of in-place air void content on the potential fatigue and rutting performance of the as-constructed RAC layer and the development of a rubber usage guide.

Products developed during the three decades included the following:

- Modifications to the Caltrans overlay design procedure to allow reduced thickness of rubber modified mixes, the primary benefit of which is in mitigating reflection cracking;
- Improvements in mix design procedures for both the gap- and open-graded mixes;
- Improvements in specifications and quality control for asphalt rubber mixes, including the prohibition of Type I binder, i.e., allow use of Type II binder only;
- Elimination of the use of dense-graded RAC mixes;
- Development of a modified binder specification; and
Development of a RAC usage guide.

The successful use of RAC has led Caltrans to expand its study of rubber modified materials as is evident by the ongoing experiments:

- Full-scale accelerated pavement testing with the HVS (heavy vehicle simulator) and a companion laboratory testing program of rubber-modified mixes to assess short- and long-term performance (the overlay materials include DGAC, RAC-G, MB-G, and MAC-G);
- Field performance of rubber-modified pavements constructed with wet or dry technologies (e.g., Firebaugh project) which include DGAC, RAC-G, RUMAC, MB Type-G, and MB Type-D; and
- RAC (rubberized asphalt concrete and MB-D) Warranty projects designed and constructed for five year performance monitoring.

The ongoing studies represent the most comprehensive research program of rubber-modified paving materials in the US. The outcome of these studies should help Caltrans to refine its strategies for the use of scrap tires in pavement-related projects. Furthermore, the results of these studies may provide the basis for updating/refining materials and construction specifications, and should better quantify the anticipated performance of rubber-modified materials perform in a wide variety of loading and environmental conditions.

Expected products from the current studies include the following:

- Improvements to mix design procedures and construction processes for the various rubber-modification technologies (wet, terminal blend, and dry); i.e., materials selection and proportioning; and
- Improvements to the warranty specification.

Two additional field studies are proposed to overcome some of the perceived barriers to increased use: the first relates to emissions and the second focuses on recycling RAC. Work plans for these studies have been developed. The construction relates to the emission testing has been completed in August 2005.

Caltrans long history with RAC mixes generally indicates that these mixes perform satisfactorily if properly designed and constructed. The experience also suggests that the most effective use of RAC is in thin overlays to retard reflection cracking. It is expected that current technology for mix design, laboratory testing and construction, as well refinements to specifications will allow Caltrans to design and build rubber modified pavements that meet or exceed the performance of conventional materials. To broaden and increase its use of scrap tires in paving applications, the most important step Caltrans can take is an aggressive, statewide campaign of technology transfer.
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1.0 INTRODUCTION

1.1 BACKGROUND

Caltrans has used rubberized asphalt concrete (RAC) mixes since the late 70s [Van Kirk, 1989]. Its first experience was with the use of crumb rubber in dense-graded asphalt concrete mixes followed by work using gap- and open-graded mixes. Currently, Caltrans uses primarily gap- and open-graded mixes for most of its projects. Caltrans’ long history with the use of these products has resulted in many advances in mix design, structural design, and changes in construction specifications and practices.

Caltrans’ early work began with the use of the wet process. With this process, the crumb rubber modifier (CRM) is blended and interacted with the asphalt cement prior to mixing with the aggregate in a hot mix plant. Typically, the asphalt cement and the CRM are interacted at high temperatures and the binder may include the addition of diluents or aromatic oils. Some of the early field studies also included the use of the dry process where the CRM was added to the aggregate in a hot mix plant before adding the asphalt cement.

In the 1990s, Caltrans began evaluating the use of modified binders (MB) that contained both CRM and polymers. These materials were blended at the refinery and generally contained lower amounts of CRM. Typical rubber contents were on the order of 5-10% and no agitation is required. Several projects were placed with this type of binder in an effort to establish improved binder specifications. More recently, the CRM content for these products has been increased to 15% for use in both laboratory and field studies.

In the 2000s, Caltrans continues to evaluate the various products (asphalt rubber, modified binders, rubber modified asphalt concrete (RUMAC, dry process)) using a variety of techniques including laboratory performance tests, accelerated pavement tests with the heavy vehicle simulator (HVS), and field studies. The results of these studies are expected to yield information that will enhance design, construction and field performance.

1.2 PURPOSE OF REPORT

This report summarizes the use of rubberized asphalt concrete (RAC) and modified binders (MB) by Caltrans. It briefly reviews some of the historical work, including descriptions of and findings from significant projects. Also, it describes the effects that these studies have had on the use of RAC in California. The report also outlines how these studies may affect Caltrans future direction with respect to the use of asphalt rubber and modified binders.

1.3 ORGANIZATION OF REPORT

The report is divided into several chapters as follows:

- Chapter 2 describes the early RAC projects and the lessons learned from these projects. These include field projects constructed from late 1970s to the present, as well as the results of accelerated pavement testing using the HVS. Almost all the early work made use of the wet process, most of which was the field blended process. Some of the field projects also made use of a modified binder (MB) which typically contained a lesser amount of rubber modifier. A brief description of the early work on the MB specification is included as well as the results of an evaluation of the field pilot studies. This chapter also describes the results of selected pavement investigations of RAC and MB projects that were constructed in the 1990s.
Chapter 3 describes Caltrans ongoing studies of various rubber modified materials including wet process high viscosity asphalt rubber binder and terminal blends, and the dry process. This includes the HVS work underway at UC Berkeley, the RAC warranty projects and the Firebaugh project. Though the laboratory testing and field monitoring are not complete, the preliminary findings, lessons learned, and expected findings are presented in this chapter.

Chapter 4 includes a summary of field projects as well conclusions and recommendations that can be made at this time. Also, it includes suggested plans and/or studies needed to ensure that remaining issues and/or barriers to increased use of RAC are addressed. These include the following: emissions, recycling RAC and technology transfer.
2.0 HISTORICAL PERSPECTIVE

2.1 THE BEGINNINGS

Caltrans began using rubberized asphalt concrete (RAC) in the late 1970s in dense-graded asphalt concrete (DGAC) mixes on an experimental basis [Shatnawi and Long, 2000]. The early RAC projects were designed using thicknesses equal to that of conventional DGAC. The mix design procedures and construction practices for RAC projects were those developed by the suppliers of the product. The most representative and significant of these early projects are described below.

2.1.1 Ravendale Project

In 1983, Caltrans designed and constructed the Ravendale project on State Route 395 in northern California. This project included various overlay strategies placed at full and reduced pavement thicknesses based on the Caltrans overlay design procedure at the time. The materials and thicknesses evaluated included the following:

- Dense-graded control sections with thicknesses of 45 mm to 150 mm (0.15 to 0.5 ft);
- Dense-graded wet process RAC, with and without a stress absorbing membrane interlayer (SAMI). Thicknesses ranged from 45 mm to 75 mm (0.15 to 0.25 ft);
- Dry process (referred to as PlusRide) with and without a SAMI. Thicknesses ranged from 45 mm to 75 mm (0.15 to 0.25 ft); and
- Double stress absorbing membranes (SAMs) made with two different asphalt rubber binders, now known as the Type I and II binders.

The DGAC control mix was placed in short segments of four different overlay thicknesses 45 mm, 60 mm, 90 mm, and 150 mm (0.15, 0.20, 0.30, and 0.50 ft).

Performance of this project was monitored throughout the 1980s. Caltrans staff observed that the RAC mixes of reduced thicknesses performed comparable to the DGAC control [Doty, 1988]. However, there were some concerns expressed with respect to the cost effectiveness of these modified materials. The PlusRide mix also performed well in comparison to the control, but no thickness reduction was proposed. This work eventually led to the development of the 1992 internal memorandum that allowed RAC mixes to be used in reduced thicknesses [Caltrans, 1992]. For example, a 45-mm thick DGAC may be replaced with a 30 mm thick RAC-G and a 120-mm thick DGAC may be replaced with a 60mm thick RAC-G. The amount of thickness reduction is dependent on the thickness of the DGAC overlay. Further, the maximum thickness for the asphalt rubber overlay was set at 60 mm (0.20 ft), primarily based on cost issues and the field experiences at Ravendale. There were some concerns over the low stability of the rubber mixes when used in thicker layers, but this issue was never documented.

2.1.2 Other Field Studies

During the late 1980s and early 1990s, Caltrans placed several RAC projects, generally using thicknesses equal to that of conventional DGAC mixes. Most of the 18 projects were constructed in Districts 2, 3 and 4 and consisted of dense- or open-graded mixes [Van Kirk, 1989]. However, there is little documentation on the project-specific mix designs and performance. In fact, most of the performance information contained in the early reports is anecdotal [Van Kirk, 1989].
Some of the later projects (after 1987) were reportedly designed using reduced thickness based on the early findings from the Ravendale study [Van Kirk, 1989; Van Kirk and Holleran, 2000]. Again, mix design and performance data for many of these projects are not well documented.

### 2.2 RAC USE IN THE 1990s

In the 1990s, Caltrans continued to study asphalt rubber mix performance through accelerated testing devices and field projects. The results of forensic studies of several field projects that exhibited premature distress are also discussed in this section.

#### 2.2.1 Accelerated Pavement Testing

During this period Caltrans continued to study the benefit of reduced RAC thickness by entering into a cooperative agreement with South Africa’s Council on Scientific and Industrial Research (CSIR). In this joint research effort a performance comparison was made of reduced-thickness ARHM-GG (now referred to as RAC-G) and a DGAC control [Rust et al., 1993]. The mixes were evaluated using the South African Heavy Vehicle Simulator (HVS) and consisted of a 75 mm thick DGAC overlay and three thinner RAC-G overlay sections with respective thicknesses of 50, 38, and 25 mm. The overlays were constructed using materials and mix design procedures conforming to Caltrans specifications. The results of this study confirmed that RAC-G overlays can be used in reduced thickness [Rust et al., 1993] to mitigate reflection cracking.

The results of the South African HVS study were the impetus for Caltrans to purchase two HVS devices for additional RAC thickness studies in cooperation with the University of California Berkeley [Harvey et al., 1999, 2001]. The results of these studies verified the CSIR findings, i.e., that RAC mixes can be used in reduced thickness to prevent reflection cracking. Based on laboratory data the RAC mixes also proved more resistant to fatigue cracking and rutting than the DGAC control. The HVS data led the researchers to conclude that the most effective use of RAC was for the control of reflection cracking [Harvey et al., 1999, 2001]. Also, the researchers noted that additional work is needed to confirm that RAC thickness reduction is applicable to new construction and/or thicker overlays.

#### 2.2.2 Field Performance Surveys

When the patents on the Types 1 and 2 asphalt rubber processes expired in the early 1990s, a number of new contractors entered the asphalt rubber market and began to place mixes for Caltrans and others. With the adoption of a reduced thickness guide in 1992, Caltrans increased the use of asphalt rubber in a number of districts. A total of 111 projects had been constructed as of 1995. Hildebrand and Van Kirk conducted a field review of 88 of these projects, most of which were RAC-G and RAC-D constructed from 1980 to 1994 [Hildebrand and Van Kirk, 1996]. Both rehabilitation and maintenance projects placed in Districts 1, 2, 3, 4, 6, 7, 8, 9, 10, and 11 were reviewed. Mixes placed after 1992 were designed using the thickness design guide that permitted reduced thickness [Caltrans, 1992].

The field reviews, all performed by Hildebrand and Van Kirk, indicated that the thin asphalt rubber overlays generally provided good performance when properly designed and constructed. However, the reviews also revealed numerous failures that were attributed to inadequate design and/or poor construction quality control. Unfortunately, the pavement rating system used was not well defined in terms of type, extent and severity of distress.

Hildebrand and Van Kirk [1996] also compared overlay projects constructed using Type I and Type II binders. Type II binders contain, in addition to the crumb rubber, high natural rubber and extender oil. They concluded that Type II binders made for more crack resistant mixes, and that crude source may...
affect performance. Also, they concluded that gap-graded RAC mixes were more resistant to raveling and cracking than the dense-graded RAC mixes. Finally, Messrs. Hildebrand and Van Kirk noted that despite early cracking and raveling, the projects performed adequately with only minor maintenance. However, the basis for these conclusions is not clearly documented in the report.

Most of the conclusions appear to be drawn based on the authors’ experience and visual assessment of field data. As a result of this study, Caltrans modified its RAC specifications to eliminate the use of Type I binders, and to make construction quality control requirements more restrictive. Some of the proposed changes in the specifications include much tighter control on the production of the binder and the mix, suggested modifications to the equipment for producing mixes, and changes in rubber and aggregate gradations.

In September 1998 representatives from Caltrans, Federal Highway Administration (FHWA), the California Integrated Waste Management Board (CIWMB), and the asphalt rubber industry met to discuss various issues concerning the use of asphalt rubber, including a follow-up to the 1995 field performance review. The new review was to evaluate the improved specifications resulting from the 1995 survey (i.e., allowing only Type II binders and improved quality control procedures).

The second field review was conducted by a Caltrans-CIWMB-industry team from January to July 1999 [Van Kirk, 1999]. A total of 113 projects, constructed using the 1995 recipe specifications, were evaluated on the basis of the following performance criteria:

- Good condition – pavements exhibited little or no distress and are expected to achieve their design life.
- Fair condition – pavements exhibited moderate distress, but are expected to achieve their design life.
- Poor condition – pavements exhibited moderate to severe distress and are not expected to achieve their design life.

Though criteria were more definitive than those used in the earlier survey, the survey still did not provide data as to type, extent, and severity of distress. Furthermore, as the projects were relatively “young,” i.e., constructed only 4 years earlier, the unlikely presence of distress made the value of the field review questionable.

Ratings of the 113 projects were as follows: 101 were “good;” 6 were “fair;” and 6 were “poor.” The six fair and poor projects (located in Districts 3, 4, 10 and 11) were to have undergone more detailed investigation to establish the cause of the problems, but these data could not be located.

Conclusions drawn by the review team were as follows:

- The improved recipe specification has significantly improved the performance of asphalt-rubber pavements; however, all the projects were less than 4 years old.
- Pumping observed on most of the fair and poor performing projects was attributed to deficiencies in the underlying base material. This indicates the need to account for existing conditions prior to placing an overlay.

Recommendations from this study, placed on the Caltrans web site 6 years after the fact, i.e., in 2005, were as follows:

- Caltrans should continue to use the improved specification on future RAC projects.
• The project reviews should be placed on the web site so others can access the information. All district personnel should be made aware of this report.
• A follow-up review of these projects should be made in the 2004-2006 time period.

Implementation of these recommendations requires a follow-up pavement condition survey in the near future, hopefully with a much better defined rating system.

2.2.3 Newberry Springs (I-40)

As a part of the FHWA’s Long Term Pavement Performance (LTPP) program, Caltrans placed test sections as a part of the Specific Pavement Study (SPS)-5. The pavements were placed in the early 1990s using several mix types: control with AR-4000; SMA with an asphalt rubber binder; and an ARMG-GG with and without a SAMI [Reese, 1997]. The results of this study, which included some laboratory performance testing, indicated that the asphalt rubber could provide rut resistant mixes if properly designed and constructed [Shatnawi and Long, 2000]. The asphalt rubber mixes did not perform as well as the control DGAC mix in laboratory tests, but there are many cases where RAC has performed better in the field than predicted based on lab tests. There is no final report on the field performance of the mixes. All field sections were monitored using the LTPP protocols and continue to be monitored by Caltrans under a contract titled “Pavement Performance Evaluation” performed by Stantec. Phase 1 of this study was completed in 2002 and Phase 2 in currently underway.

2.2.4 Interstate-5 Warranty Project

In 1993 Caltrans constructed a warranty project on I-5 in District 2 in which an asphalt concrete overlay was placed on a PCC pavement. The overlay consisted of 45 mm of RAC-G over 45 mm DGAC leveling course over a crack and seated PCC pavement [Harvey et al., 1995]. The contractor was asked to warranty the project for 5 years. The project consisted of both northbound (NB) and southbound (SB) sections that were placed by different contractors with each responsible for the individual mix design. One contractor used the newly developed Superpave mix design approach whereas the other relied on the conventional Hveem approach. The Superpave-determined binder contents were 5.2 and 6.5% for the DGAC and the RAC-G mixes, respectively. The Hveem mix design, based on air void content only, yielded a binder content of 8.5% for the RAC-G. Therefore, a compromise was made in deciding upon 7.5% for the RAC-G in the NB lanes (the average of the two mix design methods). For the SB lane, a binder content of 8.5% was used for the RAC-G. Field reviews conducted in 2000 indicated good performance in both directions with only minor raveling [Shatnawi and Long, 2000]. Additional performance monitoring and a final report are needed to complete this study.

2.2.5 Laboratory Fatigue Tests

To further verify the reduced thickness approach for RAC-G mixes, the rubber pavements industry supported a lab study of fatigue resistance on rubber modified mixes [Raad, 1993]. Controlled-strain flexural beam fatigue tests and multi-layer elastic analysis were conducted at the University of Alaska-Fairbanks [Raad, 1993]. The analysis indicated that the resulting thickness reduction was sensitive to base and subgrade moduli. Raad et al. [1993] also developed thickness equivalencies between DGAC and RAC-G based on the remaining fatigue life of pavement sections with similar initial fatigue life. By assuming base and subgrade moduli of 550 kPa and 140 kPa, respectively, they demonstrated that DGAC layer thicknesses of 150 mm and 255 mm would be equivalent to RAC-G layer thicknesses of 50 mm and 125 mm, respectively. They rationalized that the equivalent RAC-G thickness would be significantly less in the case of overlays as a result of increased support of the existing pavement structure.
In addition to the University of Alaska study, controlled-strain flexural fatigue tests were conducted at the University of California as part of the CAL/APT South African pilot project [Harvey et al., 1994]. The findings indicated that RAC-G would provide considerably longer fatigue life when compared with DGAC mixes. The results also indicated that the stiffness of rubber mixes was generally lower than that measured for conventional HMA. However, the effects of the lower stiffness and improved laboratory fatigue were not analyzed using a mechanistic-empirical analytical procedure.

2.2.6 Interstate 10, Riverside County

Initial construction of this RAC-G overlay project, PM 105.1 to 120.7, was completed in the winter 1994 [Caltrans, 1996b]. Early bleeding led Caltrans to mill off the RAC-G overlay and replace it with a DGAC overlay in the spring of 1995. Bleeding and wheel track rutting observed in the summer of 1995 was the impetus for the September 1995 failure investigation.

For the RAC-G, three mix designs were performed by District 8, and another by a private laboratory. The design binder content of 8% was selected as that corresponding to an air void content of 2%. Typically, the design binder content is that which corresponds to an air void content of 3 to 5%. The high binder content and the resulting low air void content of the as-built pavement contributed to the early distress observed in June 1995.

The DGAC overlay was placed in June 1995. There was no evidence that the distressed areas were removed prior to placement of the overlay. Within 1 month of construction bleeding was observed in the DGAC overlay, though extraction tests showed that the binder and air void contents were close to the target values. This distress is likely due to the over-asphalted underlying layer bleeding up through the DGAC overlay.

Findings reported from the failure investigation by Hannon and Van Kirk [Caltrans, 1996c] as well as those from a Caltrans Independent Analysis [Caltrans, 1996b], included the following:

- The mix design based on low voids resulted in a high binder content which caused the bleeding. Furthermore, the mix design procedure used does not reflect the range in climatic regions encountered in the state.
- The distress was also attributed to variations in aggregate composition and specific gravity, inconsistent and low rubber content which affected the binder viscosity, and a combination of heavy truck traffic and a hot climate.

Recommendations from the study included the following:

- Re-write the binder specs to require improved quality control. This includes development of improved methods to determine the binder content (e.g., ignition oven).
- Modify the mix design procedure to avoid high binder contents in hot climates.
- Provide better pavement related resources to field personnel to cope with situations like this.

A number of these changes were made after the 1995 field survey [Hildebrand and Van Kirk, 1996], including some of those recommended above. Recommendations related to RAC specifications have been a continual subject through better understanding of RAC performance and improved construction practices.
2.2.7 District 5 Asphalt Rubber Project

An asphalt rubber project was constructed in District 5 in September 1995 on SR 101 near Goleta [Caltrans, 1996a]. The completed portion of the project showed signs of early distress in 1996 following the winter rains. The early distress was limited to raveling and potholing.

The mix was a RAC-G using a Type I binder. From the forensic study a list of contributing factors emerged: specification enforcement; aggregate of marginal quality; quality control of the binder production; placement (low mix temperatures and thin lifts cool temperatures) that led to poor compaction and the premature distress. High air void content also led to stripping of the binder from the aggregate [Caltrans, 1996a].

Recommendations from this study included the following:

- Better enforcement of specifications;
- Rigorous quality control during plant production, placement and compaction; and
- Timely inspection during construction to ensure compliance.

Experience and recommendations from this and many other projects led Caltrans to improve its specification. An interim specification was completed in 1996 based upon the results of the field review. The new specification eliminated the use of Type I asphalt rubber (AR) binders and was incorporated into all AR projects in 1996.

2.2.8 District 3 Esparto Test Sections

With funding from the CIWMB, several maintenance test sections were constructed to facilitate a side-by-side performance comparison [Shatnawi and Holleran, 2003]. A 9-mile, two-lane highway, project was constructed in September 1993 on Route 16 between Esparto and Woodland in Yolo County near Sacramento.

The 11 test sections, each approximately ½ mile in length in both directions, included various asphalt rubber and conventional dense-graded strategies. The maintenance strategies selected for the various test sections were as follows:

- **Asphalt Rubber Chip Seal**
  - 12.5 mm aggregate- 0.60 gallon per square yard
- **Asphalt Rubber Hot Mix – Open-Graded**
  - 12.5 mm aggregate - 25 mm thick
  - 9.5 mm aggregate -19 mm thick
  - 9.5 mm aggregate-12.5 mm thick
- **Asphalt Rubber Hot Mix – Gap- Graded**
  - 12.5 mm aggregate - 25 mm thick
- **Dense-Graded Asphalt Concrete**
  - 12.5 mm aggregate - 25 mm thick
  - **Asphalt Rubber Hot Mix - Open-Graded (with SAMI)**
    - 12.5 mm aggregate - 25 mm thick
    - 9.5 mm aggregate -19 mm thick
    - 9.5 mm aggregate - 12.5 mm thick
- **Asphalt Rubber Hot Mix – Gap-Graded (with SAMI)**
  - 12.5 mm aggregate - 25 mm thick
- Dense-Graded Asphalt Concrete (with SAMI)
  - 12.5 mm aggregate - 25 mm thick

Caltrans Maintenance was responsible for performing the field surveys though the method of data collection was not well defined. According to Shatnawi and Holleran [2003], the performance (in terms of preventing reflection cracking) of the asphalt rubber sections after 10 years is better than the sections with conventional mixes. In addition, the asphalt rubber hot mix (open-graded with SAMI) showed the best performance when compared with the same mixes without SAMI. The asphalt rubber chip seal section has also shown good performance. The 25 mm thick sections performed better than the thinner sections in terms of cracking resistance. It should be noted that the documentation of performance for this project was not expressed in terms of type, extent and severity of pavement distress.

Caltrans Maintenance staff is preparing a final report. Information on pre- and post-construction activities is critical to isolate the effects of the various treatments on performance. As of this date performance monitoring has not accounted for the condition of the existing pavements prior to the application of the 1993 maintenance treatments.

2.3 MODIFIED BINDER STUDIES

In the 1990s Caltrans embarked on a major study (also funded by the CIWMB) to develop improved performance based specifications for modified binders (MB) [Reese, 1995]. This was followed-up with field trials to evaluate the MB specification. The advantage in transitioning from the traditional, recipe specification to a performance-related specification is obvious: the use of laboratory tests to predict field performance.

2.3.1 Initial Specification Development

Caltrans began experimenting in the 1990s with a modified binder containing both crumb rubber and polymer that could be manufactured at a terminal facility. This work was documented in a number of reports by Reese [Reese, 1995]. The end product was a modified binder specification that was based on performance related tests, including those developed through the Strategic Highway Research Program (SHRP).

The basis for the new specification were parameters known as SSD and SSV (shear susceptibility of phase angle delta and viscosity, respectively) which are not products of SHRP and are not included in SHRP Performance Graded binder specifications. These parameters and their limiting values were determined from earlier studies to maximize the fatigue performance of modified binders [Reese and Goodrich, 1993]. The MB specification met with considerable resistance from the asphalt rubber industry because they felt the new specification eliminated some good performing AR binders. The performance parameters were based on the results of the Superpave binder tests.

This work on modified binders continued into the 2000s with both laboratory and field pilot projects [Caltrans, 2002a]. It was anticipated that the use of this performance-related specification would reduce the number of “failures” experienced during the 15-year use of the original recipe specification; i.e., from 1980-1995.

2.3.2 Field Pilot Studies

Ten pilot projects were constructed between December 1997 and November 1999 to evaluate the performance of materials meeting the MB specification. The projects were located mainly in the coastal regions of California and included both dense- and gap-graded mixes placed over a range of structural
sections [Caltrans, 2002a]. Some of the binders were field blended while others came directly from a terminal. The projects were reviewed by a Caltrans-Industry group using a rating system similar to that used for the 1999 survey of RAC mixes.

Eight of the projects were rated as good, and one each was fair or poor. The conclusions from the study included the following:

- Mixes made with MB binders (both gap- and dense-graded) perform well when constructed according to specifications.
- The existing surface must be properly repaired prior to the placement of the MB mix overlay.
- Surface blemishes in the pilot projects were due to construction and workmanship problems or to existing pavement distress which was not properly removed.

Recommendations resulting from the study included the following:

- Future HVS studies (see discussion in Chapter 3) should include modified binders similar to those used in the field studies as well as those containing at least 15% CRM.
- Additional field studies should not be undertaken until the results of the proposed HVS study (lab and field tests) are complete.

The results of the proposed HVS studies should allow for an evaluation of the reduced thickness allowance for MB products compared with RAC mixes. Prior to the construction of additional full scale projects, a re-evaluation of the 10 pilot projects should be conducted.

2.3.3 Failure Investigations

Recently, two projects containing crumb rubber modifier, SM-82 and Merced-99, were investigated because of poor performance. Details on each are addressed in the following narrative.

SM-82 Project

The SM-82 project in San Mateo (District 4) is a four-lane urban arterial with landscaped median. The pavement was rehabilitated as a Capital Preventive Maintenance Program (CAPM) project in year 2000 using a 45 mm thick MB-G hot mix overlay [Caltrans, 2003d].

Distresses observed during an April 2002 field survey included rutting, shoving, bleeding and potholes [Caltrans, 2003d]. Sporadic pumping, delamination, and slippage cracking were also observed. From North Avenue to Davey Glen Road, a difference in surface texture between lanes 1 and 2 was clearly evident. In areas of severe shoving and depression, the pavement surface was reportedly tender. Exploration of these distressed areas also revealed the presence of moisture and/or uncoated, i.e., stripped aggregate. These distresses were observed primarily in north end of the project.

Major findings from the investigation include the following:

- The observed distresses (rutting, bleeding, and shoving) were related to the job mix formula (JMF). The aggregate contained considerably more “fines” than that specified. The binder content exceeded that required by JMF.
- The difference in surface texture (between lane 1 and lane 2 from North Avenue to Davey Glen Road) was the result of differences in aggregate gradation.
• The mix was not overly sensitive to moisture as the pavement in the “good” areas was performing satisfactorily. Localized stripping was attributed to the excessive moisture generated by the sprinkler system in the median.

Recommendations from this investigation included improvement of drainage in the landscaped median and removal/replacement of distressed areas with a mix of good quality. It must be emphasized that none of the distresses found could be attributed solely to the MB mix.

**Merced-99 Project**

The Merced-99 project (District 6) is located on State Route 99 near the city of Merced. A 30-mm MB-G overlay was placed in 1999 [Caltrans, 2003c]. In the field survey of May 2002 the primary distresses observed were pumping and sporadic potholes [Caltrans, 2003c]. In some areas, the pumping was very severe as fine-grained material from the underlying layers pumped through reflective cracks that ran along the edges of the northbound lane 2 and the dig out areas. The results of the field investigation revealed that the existing pavement is a composite structure consisting of both PCC (in a slab well below the surface) and an asphalt concrete (AC) surface layer. The AC surface showed varying degrees of stripping. Laboratory testing of soil samples obtained from the pavement sites indicated high moisture content in the subgrade.

The findings of this investigation were as follows:

• The observed distresses are the result of excess moisture in the subgrade that has weakened the strength of the layer, a unique pavement cross-section (with subsurface layers of different stiffness), and a combination of heavy wheel loading and excess moisture below the surface.
• The distress is not at all related to the modified binder used in the project.

A follow-up site visit conducted in June 2003 indicated that the pavement condition had not deteriorated such that immediate repair is unnecessary. The problem with excess moisture should be addressed by improving pavement drainage characteristics. Recommended solutions also included improvements of pavement structural capacity through overlays.

**2.4 RAC RECYCLING STUDIES**

Caltrans has experimented with various methods of recycling conventional and CRM-modified paving materials, including hot plant recycling, and forms of hot and cold in-place recycling (HIPR and CIPR) including full depth reclamation [Caltrans, 2005a]. According to former Caltrans engineer Jack Van Kirk, Caltrans experimented with recycling CRM-modified materials on two projects in the early 1990s. The first, a 1994 project on Route 40 (District 8), reportedly included reclaiming and recycling RAC. However, District 8 personnel assigned to search for related records in response to inquiries were unable to locate any information to confirm this.

The other recycling project was located in District 3 on Route 89 near Sierraville, and it included an asphalt rubber chip seal. The CRM-modified chip seal material on the surface did not seem to cause any problems. However, it was reported that during hot plant recycling of the reclaimed asphalt pavement (RAP) and chip seal material into a conventional recycled AC mix, “ropes” of crack sealer had to be manually removed from the RAP feed belt. Caltrans reported that recycled mix looked “good” immediately after placement. However, the pavement failed severely within one or two years after construction. No specific information regarding the type or cause of failure could be readily located in the District 3 files and it is not clear if the plant-recycled pavement was subsequently removed and
replaced or simply overlaid. An adjacent pavement section also surfaced with asphalt rubber chip seal was recycled cold in-place as a base course and overlaid with AC.

Other agencies have recycled RAC with no major problems. A detailed discussion of the experiences of others can be found in the report titled “Feasibility of Recycling Rubber Modified Paving Materials” [Caltrans, 2005a]. Since this issue often is perceived as a barrier to use of asphalt rubber mixes, it is recommended that Caltrans include a RAC recycling project in a future study.

2.5 RAC STUDIES IN THE 2000S

To improve upon the understanding and performance of RAC pavements, two studies were recently been undertaken: the first dealt with the effect of compaction on RAC performance, the second led to the development of a RAC usage guide for Caltrans.

2.5.1 El Centro Project

The El Centro project involved overlaying approximately 32 miles of Interstate 8 with 60 mm of RAC-G near the town of El Centro [Caltrans, 2003b]. Construction began in November 2000 and was completed in May 2001. There were concerns with the project in that the specified value of relative compaction of 96% (relative to a compacted Hveem sample) was not achieved. The results showed that there were many instances where the relative compaction was below 93%. Following construction, it was noted that the relative compaction in the traffic areas was increasing. In June and December 2001, additional cores were taken from several locations throughout the project. It was found that the relative compaction at the majority of the locations had increased to the specified 96%.

Further study was undertaken in 2003 to evaluate the effects of in-place air void content on the potential fatigue and rutting performance of the as-constructed RAC layer. Core and slab samples were taken from traffic lanes as well as the shoulder. The average in-place air void content varied from 6.8% to 12.9% (based on the Rice Gravity method). Fatigue and rutting tests were conducted in accordance with AASHTO T-321 and T-320, respectively. Fatigue testing was conducted at 20°C, whereas the rut testing was conducted at 55°C.

The findings from the study indicated that the air void content of the RAC mix specimens had a significant effect on both the fatigue and rutting performance of the RAC materials. For example, a 2 percent increase in air void content of the RAC mix specimens resulted in a decrease in fatigue life of about 60% and an increase in permanent strain of about 41%. New pay factors were also developed for the RAC mixes. An increase in air void content (equivalent to a decrease in relative compaction from 96 to 94%) would result in an 18% pay reduction for this project compared to a 9% pay reduction using current Caltrans pay reduction factors. The pay reduction factors developed in this single study are also more severe than those currently proposed by the Caltrans Asphalt Concrete Task Group.

Although appropriate for the El Centro project, these pay factors require validation with data from other projects. This information should be shared with the Resident Engineers (RE) and others in Caltrans who might encounter similar issues.

2.5.2 Caltrans Asphalt Rubber Usage Guide

In part, because of the pavement failures and the early distress on some of the RAC pavements, Caltrans developed an Asphalt Rubber Usage Guide [Caltrans, 2003a]. This guide was developed to assist Caltrans personnel with the design and construction of asphalt rubber hot mixes and chip seals. It provides a “state of the practice” for materials selection and use, design, production and construction.
Also, it provides guidelines for quality control and assurance for the binder, chip seals and hot mixes. The guide is intended to help Caltrans to optimize the use of asphalt rubber materials to obtain the advertised benefits. The guide provides details on the following:

- Overview of the various asphalt rubber materials;
- Details on binder design procedures;
- Benefits and limitations of asphalt rubber materials;
- Mix design criteria;
- Guidelines for construction and inspection; and
- Cost and environmental considerations.

The guide represents the best practices and is available on the Caltrans web-site at the following location (http://www.dot.ca.gov/hq/esc/Translab/pubs/Caltrans_Asphalt_Rubber_Usage_Guide.pdf). It is a valuable document, but unfortunately at two recent Caltrans seminars on RAC, most of the Caltrans personnel were not aware of the guide. It would be useful to evaluate the impact this guide has had on Caltrans practices.

2.6 PRODUCTS DEVELOPED

As a result of the work in the 1980s through the early 2000s, Caltrans has developed a number of products to enhance design and construction of crumb rubber modified pavements. These products include the following:

- Modifications to the Caltrans overlay design procedure have been made to allow a thickness reduction of 2:1 for overlays. This has been verified in HVS studies but applies to RAC-G mixes only. The use of asphalt rubber in open-graded mixes does not provide the same structural contribution.
- Mix design procedures for both the gap- and open-graded mixes have been improved and modified as a result of field experiences. Changes made over the years have accommodated the need to vary the void content as a function of climate and traffic.
- Improvements to specifications included materials (use of Type II binders only) and tighter quality control on the crumb rubber, aggregate gradation, and the asphalt rubber binder.
- Eliminated the use of dense-graded mixes which led to early raveling of several RAC pavements. The dense-graded mixes did not have sufficient voids to accommodate the coarse crumb rubber.
- Development of a modified binder specification which continues to be used in field test sections and in accelerated pavement test studies. The results of the accelerated pavement studies and the associated lab testing can be used to establish the cost effectiveness of this product.
- Development of an asphalt rubber usage guide to aid field personnel in working with RAC materials.

2.7 LESSONS LEARNED

The results of the studies described in this chapter suggest the following:

- Caltrans has done a great deal of work to help improve the design and construction practices of RAC pavements. Caltrans is one of the leaders in the USA in its use.
• The studies undertaken by Caltrans are often not completed. The reasons for this are likely due to the lack of a champion or sponsor for a given study from beginning to end, and/or a general shortage of resources.

• Much of the field work conducted did not have an experimental plan and as a result the findings are often not as good as they could be. Many of the conclusions drawn appear to be based on personal experience and lack of specific data to support the conclusions.

• Caltrans needs to improve its technology transfer and to monitor how this information is used to improve on current practices. Timely reporting and distribution of guides, field studies and failure investigations is important. The developed information needs to reach the correct people in Caltrans in a timely fashion.

• There are still perceived barriers to the use of RAC mixes. These need to be overcome through improved technology transfer programs.
3.0 CURRENT STUDIES

Caltrans has several studies underway dealing with rubber modified mixes. This chapter outlines the framework of each as noted below:

- Scope and purpose
- Hypothesis or variables considered
- Status of the project, including preliminary results
- Expected findings from the studies

Most of these projects followed the generic experimental design prepared for Caltrans and include laboratory testing to allow a comparison of likely performance [Caltrans, 2005b].

3.1 HVS STUDY AT UC-BERKELEY

The University of California is currently involved in a study of the performance of several rubber modified mixes by means of full-scale accelerated pavement testing with the HVS. The HVS testing is supplemented with companion laboratory testing. The purpose of this study is to evaluate the short and long-term performance of various rubber modified binder overlays [University of California Berkeley, 2003]. In this study, performance is measured in terms of fatigue cracking, reflective cracking, and rutting. The six overlay strategies included in the evaluation are as follows:

- Full thickness (90-mm) dense-graded asphalt concrete (DGAC) overlay (control);
- Half thickness (45-mm) rubberized asphalt concrete Type G (RAC-G) overlay (control);
- Half thickness (45-mm) MB-4 Type G overlay;
- Full thickness (90-mm) MB-4 Type G overlay;
- Half thickness (45-mm) MB 15% rubber Type G overlay; and
- Half thickness (45-mm) MAC 15% rubber Type G overlay.

All six overlay mixes were constructed on a uniform test section constructed at the UCB Richmond Field Station in September 2001. The test pavement consists of asphalt concrete (AC), aggregate base, and re-compacted cohesive sub-grade soil. HVS loading was applied from December 2001 to April 2003. The overlays were constructed in June 2003.

As noted above, the testing program encompasses both HVS loading and laboratory performance testing. The objective of the HVS testing is to evaluate the rutting and fatigue and reflection cracking performance of various overlay mixes. In this study, the rutting performance was measured under high temperature (50±2°C) while the fatigue performance was measured under moderate temperature (20±2°C). The high temperature tests were conducted first followed by the moderate temperature tests.

The rutting test program was completed in January 2004. The fatigue test program started in January 2004 with an expected completion in early 2006. Researchers at the UC-PPRC (Partnered Pavement Research Center) reported that mixes are proving to be more crack resistant and less rut resistant than originally anticipated. In fact, some rutting occurred during the 20°C testing. Test temperatures have been lowered to try to accelerate the fatigue cracking without exceeding the surface rutting failure criterion of 12.5 mm. Specific changes in the testing program included reducing the testing temperature from 20°C to 15°C and increasing the load from 80 kN to 100 kN after 1,000,000 repetitions.

The purpose of the laboratory test program is twofold: to determine the material properties of the test section; and to compare the laboratory-measured performance to that measured as a result of HVS
loading. The laboratory program for the underlying test pavement included tests on asphalt concrete, aggregate, and sub-grade soil for determination of material properties that are important to the evaluation and comparison of overlay performance. All lab testing has been completed, and a draft report is undergoing internal review by the UC PPRC team. This report should be available in the fall of 2005. This information will be especially important in evaluating the structural contribution of the various binders using a mechanistic-empirical approach to overlay design following the approach developed by MACTEC as a part of a current CIWMB-Caltrans project.

The laboratory testing program for the overlay materials includes the same tests performed on the DGAC of the underlying pavement plus shear and fatigue tests for samples of each overlay mix and components thereof taken during the construction of the sections. The lab tests are being conducted on both field-mixed lab-compacted (FMLC) and lab-mixed and lab-compacted (LMLC) specimens. The specimen preparation is nearly complete and testing has started [Tsai, 2005].

The HVS study includes various field measurements: FWD deflections, deformation, profile, temperature, mix density, moisture content, and visual inspection for type and amount of cracking. These activities have been conducted monthly. Trench studies are also planned at the end of the project.

Findings from this study will address the relative performance (rutting, fatigue and reflective cracking) of the various overlay mixes placed over cracked test pavement. Also, the results of this study should allow one to quantify the effect of overlay thickness on performance.

### 3.2 RAC WARRANTY PROJECTS

In 2002, Caltrans initiated a field experiment that included five pilot projects for roadway rehabilitation containing specifications for rubberized asphalt concrete (RAC) and modified binder (MB) mix [Caltrans, 2002b, 2002c]. All five projects included a 5-year warranty for materials (RAC or MB) and workmanship.

The overall purpose of the experiment was to provide a “level playing field” for evaluating the different rubber-modified mixes that contain a minimum of 15% scrap tire rubber constructed using the “wet process” (asphalt rubber or MB). Unfortunately, a control section of DGAC was not included in any of the projects.

The following table shows the project locations, materials placed and construction dates.

<table>
<thead>
<tr>
<th>District</th>
<th>County</th>
<th>Route</th>
<th>Kilopost (KP) Limits</th>
<th>Mix Type</th>
<th>Construction Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>Lassen</td>
<td>395</td>
<td>19.0 – 39.9</td>
<td>MB-D</td>
<td>8/04</td>
</tr>
<tr>
<td>06</td>
<td>Fresno</td>
<td>33</td>
<td>100.4 – 111.7</td>
<td>RAC-G</td>
<td>8/03</td>
</tr>
<tr>
<td>07</td>
<td>Ventura</td>
<td>150</td>
<td>24.4 – 38.6</td>
<td>RAC-G</td>
<td>10/02</td>
</tr>
<tr>
<td>10</td>
<td>Merced</td>
<td>140</td>
<td>43.4 – 48.6</td>
<td>RAC-G</td>
<td>9/03</td>
</tr>
<tr>
<td>11</td>
<td>San Diego</td>
<td>75</td>
<td>17.7 – 28.0</td>
<td>RAC-G</td>
<td>5/03</td>
</tr>
</tbody>
</table>

Within each project, several performance evaluation sections (PESs) were established. Each PES is 152 m (500 feet) long and one lane wide. The number of PESs selected within a given project was dependent upon the observed range in structural support (as represented by pavement cross section and measured deflections in terms of relative high, medium, and low) and distress. A construction report documents the establishment of these sections and the associated construction activities elsewhere [Caltrans, 2005f].

Pavement performance monitoring is expected to be conducted on an annual basis for five years. The latest monitoring was conducted in December 2004 for the Lassen project and in February 2005 for the
Ventura, Fresno, Merced, and San Diego projects. As of this date all pavements appear to be performing well with little or no measurable distress recorded [Caltrans, 2005g].

The expected outcome from these pilot projects are as follows:

- Determination of the efficacy of the warranty specification; and
- Performance assessment of four field mixes (wet process high viscosity) RAC products and one terminal-blend wet process product over a 5-year period.

The lack of a control section is unfortunate in that comparisons with conventional materials in a given environment will not be possible.

### 3.3 Firebaugh Project

The Firebaugh project was constructed in June 2004 on State Route 33 near the town of Firebaugh [Caltrans, 2005d]. The purpose of the study is to evaluate the field performance of rubber-modified test sections of various thicknesses with conventional DGAC. Also, this study will allow an assessment of the various rubber-modification technologies in terms of materials specifications and constructability.

The pavement test sections include nine test sections: a Type A DGAC control section (conventional process), RAC-G (wet process) 45 and 90 mm thick sections, Rubber Modified Asphalt Concrete – Gap Graded (RUMAC, dry process) 45 and 90 mm thick sections, Type-G Modified Binder (MB, terminal blend process) 45 and 90 mm thick sections, and Type-D MB 45 and 90 mm thick sections. The project specifications required the MB binders to have at least 15% rubber by weight of asphalt.

Caltrans obtained materials and field samples during the construction for performance testing in the lab. The lab testing included both volumetric (air void content) and performance testing (rutting, fatigue, and Hamburg wheel tracking). The laboratory testing, all of which is complete, indicates that the pavements are likely to perform differently in terms of resistance to rutting and cracking.

In ranking the relative lab performance of each mix, a simple method, based on a 1-5 scale with 5 being the best in performance, was used. A summary is provided below [Caltrans, 2005e]:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Rutting Performance</th>
<th>Fatigue Performance</th>
<th>Hamburg Wheel Tracking Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40°C 50°C 60°C Total</td>
<td>400 µε 600 µε Total</td>
<td>50°C Initiation of Moisture Damage (MD) Rate of MD after Initiation Total</td>
</tr>
<tr>
<td>RAC-G</td>
<td>3 4 3 10</td>
<td>4 2 6</td>
<td>4 4 2 4 10</td>
</tr>
<tr>
<td>RUMAC</td>
<td>2 5 2 9</td>
<td>2 4 6</td>
<td>5 5 4 14</td>
</tr>
<tr>
<td>MB-G</td>
<td>1 3 4 8</td>
<td>5 5 10</td>
<td>1 2 1 4</td>
</tr>
<tr>
<td>MB-D</td>
<td>5 2 5 12</td>
<td>1 3 4</td>
<td>2 1 3 6</td>
</tr>
<tr>
<td>DGAC</td>
<td>4 1 1 6</td>
<td>3 1 4</td>
<td>3 3 5 11</td>
</tr>
</tbody>
</table>

The results generally indicate the MB-D and the RAC-G perform best in terms of resistance to rutting, while the MB-G performs best in terms of fatigue. The results from the Hamburg wheel tracking test indicate that the RUMAC is the least susceptible to moisture-induced damage.

Similar testing is underway at UC Berkeley on materials from the HVS test sections. Though the results are not available, conversations with the investigators suggest that the MB binders are performing best in fatigue for these materials as well. Again, the actual impact on pavement life and/or design practices...
must be evaluated using a mechanistic-empirical design approach. This has not been completed for either of these projects.

Construction experience, field observation, and initial field performance from the Firebaugh project indicate that all three processes (wet, terminal blend, and dry) can be used satisfactorily during the construction. From a site visit in June 2005 it appears that the RAC-G, RUMAC, MB-D, and DGAC mixes are performing well. Bleeding in the wheel path of the MB-G mix is indicative of excessive asphalt and/or low air void content. Additional field coring in this area may be necessary to confirm/refute this.

The results of the Firebaugh project should provide insight on the following:

- Relative lab and field performance of the DGAC control with the RAC and MB materials;
- Constructability of asphalt rubber using the wet and dry processes;
- Influence of layer thickness; and
- Field performance vs. HVS and laboratory performance.

### 3.4 SUMMARY

There are three types of studies currently underway:

- Full-scale accelerated pavement testing with the HVS (heavy vehicle simulator) and companion laboratory testing of rubber-modified mixes to assess short- and long-term performance of DGAC, RAC-G, MB-G, and MAC-G overlay materials;
- Field performance of rubber-modified pavements constructed with wet or dry technologies (e.g., Firebaugh project which includes DGAC, RAC-G, RUMAC, MB Type-G, and MB Type-D); and
- RAC-G and MB-D Warranty projects constructed for five year performance monitoring.

The following is a summary of the mix types and layer thicknesses involved in these studies:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>UCB PPRC</th>
<th>Firebaugh</th>
<th>RAC Warranty</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGAC</td>
<td>90 mm</td>
<td>90 mm</td>
<td></td>
</tr>
<tr>
<td>RAC-G</td>
<td>45 mm</td>
<td>45 mm, 90 mm</td>
<td>Thickness varies</td>
</tr>
<tr>
<td>RUMAC</td>
<td>45 mm, 90 mm</td>
<td>45 mm, 90 mm</td>
<td></td>
</tr>
<tr>
<td>MB-G</td>
<td>45 mm, 90 mm</td>
<td>45 mm, 90 mm</td>
<td></td>
</tr>
<tr>
<td>MB-D</td>
<td>45 mm, 90 mm</td>
<td>60 mm</td>
<td></td>
</tr>
<tr>
<td>MB 15% G</td>
<td>45 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAC-G</td>
<td>45 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.5 EXPECTED PRODUCTS FROM CURRENT STUDIES

The ongoing studies represent the most comprehensive research study of rubber-modified paving materials in the US. The outcome of these studies should help Caltrans to confirm/refute the validity of its strategies for the use of scrap tires in pavement-related projects. Furthermore, the results of these studies should provide the basis for updating/refining materials and construction specifications, and should better quantify the anticipated performance of rubber-modified materials in a wide variety of loading and environmental conditions.
Expected products from the current studies include the following:

- Improvements to mix design procedures and construction processes for the various rubber-modification technologies (wet, terminal blend, and dry); and
- Improvements to the warranty specification.

3.6 LESSONS LEARNED

For existing and future studies to produce useful results, Caltrans should consider the following steps:

- Identify a champion or sponsor for each project, as well as the individual responsible for performance monitoring and documentation of same.
- Develop experimental designs and work plans for each project.
- Implement and monitor all projects in accordance with the experimental design and work plan.
- Communicate effectively with all project-related staff, including its industry counterparts.
- Document ALL project-related activities from project award to mix design, pre-construction, construction and post-construction performance monitoring.

As noted previously, most of this information on project planning and data collection is provided in the generic experimental design report [Caltrans, 2005b].

Although not complete, the projects described in this chapter clearly indicate that consistency in work plans and implementation of same are critical to Caltrans assessment of the effectiveness of rubber-modified materials in paving applications. Specifically, lessons learned include the following:

- The HVS study has a well-developed plan that is being followed. The results from the study should yield useful information on the design and performance of mixes.
- The RAC warranty projects were initiated by top management without an experimental plan. Although a data collection plan was subsequently developed, it was not followed consistently for the various projects. Furthermore, the lack of “control” sections in the warranty projects severely compromises the value of this study. It precludes the possibility of a direct performance comparison between conventional materials and rubber-modified materials. The study also demonstrated the difficulty in recruiting field projects. Without clear definition of the objectives and potential benefits as well as initial involvement, district personnel are, justifiably, reluctant to participate in these sorts of activities.
- The Firebaugh project included most of the elements of the experimental design process now recommended by Caltrans. The field sections include a control such that relative performance of different mixes placed in different thicknesses can be monitored.

For all studies there is a continuing need to improve the technology transfer component.
4.0 FUTURE STUDIES

4.1 SUMMARY

An extensive body of literature has been developed by Caltrans and others on the various uses of crumb rubber which cover a wide range of approaches [Caltrans, 2005h]. The use of CRM modified binders in California has yielded variable results for a number of reasons; however, these materials have been shown to have great potential for use in pavements to resist reflection cracking, to enhance durability, and reduce the needs for maintenance and repairs. There have been numerous successes, but also some major failures, which seem to have a greater impact on the overall perception on the performance or quality of these materials than any report documenting the successful applications.

Caltrans is one of four states where crumb rubber modification of asphalt paving materials has become routine. The others are Arizona, Florida and Texas. It is no coincidence that these are the locations where the materials were championed by local suppliers or by the DOT. Suppliers strongly encouraged the use and supplied technical information to help develop and optimize the systems and the materials. Where the modified materials were fostered, they succeeded on a regular basis; any failures were quickly remedied and the design procedures and/or construction practices modified. Standard specifications were developed and used on a regular basis which enhanced contractor proficiency with handling and construction. For example, based on public demand, Arizona DOT recently elected to place asphalt rubber friction course overlays over most of the portland cement concrete pavements in the Phoenix Metropolitan Area expectedly to reduce traffic-generated noise by a minimum of 4 dBA [Scofield and Donavan, 2003].

It is a coincidence that the routine users are all Sunbelt states which has led to the common misperception that rubber modified binders only work in hot climates. That is clearly not the case. California and Arizona encompass climatic zones with temperature extremes from desert to mountainous elevations. Success, and indeed failures can be found in any of these climatic zones. However, with good design and construction, the successes far outnumber the failures, just like with any other material.

Why are rubber modified mixes not more widely used, both in Caltrans and in other states? Are the reasons technical, operational, environmental and/or economic? In other words, what barriers remain? It appears, based on the state of the practice [Caltrans, 2005h] that most of the technical and operational barriers have been surmounted. Moreover, paving mixes can be designed and placed with conventional equipment. Instructional materials are readily available through the California Rubberized Asphalt Technology Centers or from the Caltrans Asphalt Rubber Usage Guide which is available on the Internet.

There are, however, perceived barriers which include environmental and economic aspects. For example, Caltrans is not permitted to construct pavements with modified binders in some regions because of air quality concerns, i.e., emissions, despite studies done elsewhere that negate these concerns. Also, from the air quality perspective there is reluctance to recycle rubber modified materials. Again, work done elsewhere indicates that recycling rubber modified materials is not problematic [Caltrans, 2005a].

In some quarters there are issues with material cost. Admittedly, the initial cost is higher, but depending on the number of suppliers in an area, the cost differential between RAC and conventional mixes is diminishing. The life cycle cost comparisons show that RAC mixes are cost effective [Caltrans, 2005h]. This needs to be communicated better through technology transfer programs.

The question that remains is what, if any, are the studies needed to overcome the remaining environmental and economic barriers. To address the environmental concerns, Caltrans District 1 conducted a field study in the summer of 2005 that involved testing emissions during plant production of...
a variety of rubber modified products. Another study would be a similar project to address concerns with recycling RAC.

Probably the most important effort should be directed towards improving technology transfer. Several strategies should be considered: distribution of refined/new guides; conventional classroom and/or web-based training for Caltrans and industry personnel.

4.2 CONCLUSIONS

Caltrans has been involved with rubber modified asphalt materials since the 1970s. As a result, it has a long history with the use of these materials in pavements throughout the state. It has made significant contributions in many areas including the following:

- Caltrans is the only state in the US allowing reduced thickness when using RAC-G in thin overlays;
- Improved mix design and materials specifications through laboratory and field studies;
- Numerous field projects to facilitate performance comparisons of the various rubber modified materials. However, the conclusions and recommendations from these studies were not always well developed or implemented;
- Development of a usage guide to assist Caltrans personnel in making better decisions as to the most effective use of rubber modified materials; and
- Providing training opportunities to promote the use of these products.

The CIWMB has supported some of the studies described in this report. It funded much of the early work on the development of the MB specifications, the test road on maintenance treatments in Yolo County, and work (since July 2004) dealing with the state of the practice, experimental plans, recycling, and guidelines for materials and construction. Also, the CIWMB funded a technology transfer effort which has yet to be implemented, but is the key to improving the state of the practice within the state.

4.3 RECOMMENDATIONS FOR TECHNOLOGY TRANSFER

To broaden and increase Caltrans use of scrap tires in paving applications the most important step is that taken in the direction of an aggressive, statewide campaign of technology transfer. Specifically, the recommendations for Caltrans are as follows:

- Ensure that all reports on RAC are placed on the website and/or distributed to those who are involved in working with these materials.
- Develop and maintain a strong technology transfer program to keep field personnel apprised of the latest developments. This could include classroom and/or web-based training.
- Continue to interact with other agencies working with these materials. Interchange of ideas between state and local agencies is an excellent method of technology transfer.
- Develop an implementation plan to ensure that all future studies have a “champion” to nurture a project from design, through construction and documentation of long-term performance.

4.4 RECOMMENDED FIELD STUDIES

Two field studies were proposed to overcome some of the perceived barriers to increased use. The first relates to emissions and was undertaken in the summer of 2005; the second focuses on recycling RAC and should be completed as soon as practical.
4.4.1 District 1 Project

The District 1 rubberized asphalt concrete (RAC) project is located on State Route 20 in Mendocino County [Caltrans, 2005c]. The North Coast Mendocino and Lake County Air Quality Management Districts requested emissions testing during plant production of the crumb rubber modified mixes. The study includes four test sections: DGAC control, RAC-G, MB-D, and RUMAC. To assist field monitoring, one performance evaluation section (152-m long) within each test section was established. For METS, the primary objectives of this study are as follows:

- Assess relative performance (field and laboratory) of the DGAC, RAC-G, MB-D, and RUMAC mixes;
- Evaluate constructability of RAC using the wet high viscosity and terminal blend processes and the dry process; and
- Compare field and lab performance of the District 1 materials with those from the Firebaugh project and the HVS studies of similar mixes.

Construction began in August 9, 2005 and was completed on August 25, 2005 [Caltrans, 2005c]. During the construction, METS collected samples for laboratory performance testing. Both volumetric (air void content) and performance testing (fatigue, rutting, and Hamburg wheel tracking) are included. The 5-year field monitoring includes FWD deflection testing and visual distress surveys on the performance evaluation sections.

Expected deliverables from this project include the following:

- Verification of the air quality issues for the various products placed;
- Relative performance assessment (lab and field) of DGAC, RAC-G, MB-G, and RUMAC mixes;
- Evaluation of constructability of asphalt rubber using the wet, dry, and terminal blend processes;
- Evaluation, improvement, and implementation of asphalt rubber specifications; and
- Comparison of field and lab performance with that of materials from the Firebaugh project and the HVS studies.

Should emissions data confirm that plant production of various rubber modified mixes is not problematic, it should pave the way for further use of such materials in District 1 as well as statewide.

4.4.2 Proposed Recycling RAC project

Two studies were proposed as a result of a study on the feasibility of recycling RAC in California, a lab study and a field study [Caltrans, 2005a]. Based on the results of NCHRP 9-12, the lab study has been deemed unnecessary, as reclaimed RAC will be incorporated in DGAC mixes at a level of 15% or less by weight of aggregate.

Experimental Plan for Field Validation

The purpose of the field validation phase of the study is to evaluate under actual field conditions the plant production and performance of DGAC paving mixes produced from a combination of virgin aggregates and asphalt cement and reclaimed RAC. Of particular interest are operational aspects of reclaiming and recycling RAC materials, including impacts of CRM-modification on milling equipment and efficiency,
handling of reclaimed RAC and chip seal materials, introduction of such materials into the AC plant, emissions, etc.

The experimental plan shall be developed according to the “Generic Experimental Design for Product/Strategy Evaluation - Crumb Rubber Modified Materials” [Caltrans, 2005b]. Flexibility is a requirement for conducting field experiments, and it may be necessary to make some changes depending on findings of the laboratory study, the availability of candidate projects and the ability of the respective districts to support the experiment. However, maintaining a sound experimental and data collection plan is essential to obtaining useful results, and the effects of any changes to the proposed evaluation plan should be carefully considered.

**Expected Deliverables**

The expected deliverables from the validation phase are long term items, which include:

- A direct comparison of field performance of traditional DGAC with DGAC pavements constructed using a combination of virgin asphalt mix and recycled RAC.
- Comparison of field performance with laboratory performance test results.
- Overall cost comparison.

Five years is not sufficient to determine or compare the long-term performance of the recycled RAC mixes; however, any serious deficiencies are likely to manifest within that period. Therefore, it is recommended that these projects continue to be evaluated after the initial 5-year monitoring period has been completed, for the life of the subject recycled AC pavements.
5.0 REFERENCES

REFERENCES CITED


OTHER REFERENCES


