Rubberized Asphalt Concrete

Submitted to:  Dr. DingXin Cheng
Professor

Submitted by:  Israel J. Patterson
Undergraduate Student

Date Due:  December 12, 2007

Date Submitted:  December 12, 2007

California State University
Chico, California
# Table of Contents

Introduction...........................................................................................................1-2

History..................................................................................................................2-5

Composition and Production Process.................................................................6-8

Application...........................................................................................................8-11

Environmental Benefits.....................................................................................11-14

Future of Rubberized Asphalt Concrete............................................................14-16

Works Cited.........................................................................................................17-19
Introduction:

What common external factor do a Ford, Toyota, Dodge, and Chevy vehicle possess? Answer: the road on which they drive. According to data provided by the United States Department of Transportation’s Federal Highway Administration in 2003, there were over two hundred and thirty-one million vehicles traveling on the United States roadways, making transportation by freeways, highways, and local roads the number one way to travel (Wikipedia 1). In general, most people never pay much attention to the roadway on which they drive other than to navigate their vehicle or to complain when they drive over a pothole. Yet to a few, when they look at a roadway, they see much more. These people see what lies beneath the signs of deterioration; they see angles of grade, sub-base materials, compaction requirements, and pavement surface layers. Every element and design that come together to create a roadway are vital to the safety of the passengers in the vehicles traveling on it. However, environmentally-aware engineers that design roadways are not only looking out for the passengers in the cars that happen to be traveling on a particular road, they are also considering the safety and welfare of the entire community and environment.

Rubberized asphalt concrete is a revolutionary roadway pavement material that was designed to utilize discarded vehicle tires (waste tires) in addition to conventional paving materials in order to produce a superior driving surface. The history of the development of rubberized asphalt concrete (RAC) spans a period of approximately forty years and contains stories of both success and failure. However, through perseverance, RAC’s composition and production process has been refined, and RAC is now gaining popularity among engineers for its many life-cycle and maintenance benefits and among the political crowd for its environmental benefits. The amount of rubberized asphalt concrete used in roadway construction is increasing
throughout the United States, and though RAC has gone through some setbacks during its
development, the future of RAC looks to be secure.

**History:**

The following history of rubberized asphalt concrete is a summery from a combination of
the listed resources: the California Department of Transportation’s *Asphalt Rubber Usage Guide*,
R.G. Hicks, P.E. and his associates’ *Asphalt Rubber Design and Construction Guide Volume I*,
the Arizona Department of Transportation’s *History of Rubberized Asphalt*, and information
obtained on the Rubber Pavements Association website.

The Rubberized Pavement Association website states that “engineers and chemists have
been trying to incorporate rubber into asphalt since the 1920’s” (RPA 1). The California
Department of Transportation gives the time frame when asphalt rubber (AR) innovation started
as being towards the end of the 1930’s. By the 1950’s, an in-depth evaluation had been
preformed by the Bureau of Public Roads investigating *The effects of Various Rubbers on the
Properties of Petroleum Asphalts* along with a *Laboratory Study of Rubber-Asphalt Paving
Mixtures*. The second study used rubber from waste tire treads as one of their rubber samples.
The rubber samples were combined with asphalt concrete in wet and dry mixtures as part of the
study. As studies, interest, and support continued to climb in the development of AR, the
Asphalt Institute presented five written arrangements and a discussion session in their
Symposium on Rubber in Asphalt in March of 1960 (California DOT 1-2).

Even with the extensive research conducted, it was not until the 1960’s that the idea to
incorporate rubber from waste tires with other roadway materials ever brought true success; this
was credited to Charles H. McDonald. Arizona’s Department of Transportation along with Atlos
Rubber and the Sahuaro Petroleum and Asphalt Company collaborated with McDonald in his
efforts to formulate a commercial binder system. McDonald was the main contributor to the successful asphalt rubber mixing through the “wet process.” Hot mix applications of asphalt rubber for patch and repair work were another of McDonald’s standard practices (California DOT 1-2).

Due to the fact that Charles McDonald worked for the City of Phoenix, Arizona, the state of Arizona was one of the first states to use rubberized asphalt in their “chip seal” program in 1964. This elementary form of chip seal was made from “a mixture of rubberized asphalt and gravel,” according to Arizona’s Department of Transportation (Arizona DTP 1). Surprisingly, this “temporary” solution to the deteriorating roadway turned out to be a twenty-year fix.

It was not until 1975 that California’s Caltrans joined in and started using asphalt rubber in laboratory experiments. They also used AR in two small chip seal projects in order to monitor the success of the projects. By 1980, Caltrans applied a 30 millimeter-thick layer of rubberized asphalt concrete on top of a 60 millimeter-thick layer of dense graded asphalt concrete (DGAC) that had been placed over a section of extremely damaged roadway in Strawberry, California. According to the reports, the Strawberry project along with another RAC application site at Donner Summit, both located at high elevations and visited by winter snows, held up well even with the cold weather and use of tire chains. Studies of different applications of RAC were continued by Caltrans over the next few years. Different thicknesses of RAC were applied to multiple underlying materials, and careful observations were made in relation to how each application withstood normal wear-and-tear along with environmental elements such as summer heat and winter snow. Through the studies, Caltrans was able to determine that RAC was indeed the better choice when comparing conventional DAGC and RAC. Rubberized asphalt concrete
was able to be applied in thinner applications than those of DAGC while exhibiting less signs of damage over time.

As California moved forward in case studies of RAC, other states were also making progress in RAC applications. Arizona started “using an asphalt rubber hot mix to add a one-inch overlay to prolong the life of streets” in 1989 (Arizona DOT 1). There was great success with these applications such as: the ability of the new pavement to completely cover the signs of deterioration from the underlying roadway, the increased stability and the decreased slickness in relation to traditional asphalts, the dramatic decline in the noise volume of traveling vehicles, and the ability to provide a less bumpy roadway. This use of RAC continued throughout the 1990’s as Arizona used 450,000 tons of RAC to cover over 200 miles of roadway. The success was so substantial in their projects that Dobbins Road, which was resurfaced in 1989, was not scheduled for possible resurfacing again until 2007 (Arizona DOT 2).

Bouzid Choubane, one of the writers of the *Long Term Performance Evaluation of Asphalt-Rubber Surface Mixes*, says that Florida was another state utilizing rubber asphalt in their roadway design as early as the end of the 1970’s. Their primary use for AR was “as a stress absorbing membrane interlayer and as a moisture barrier” until 1988, when the Florida legislature voted in Senate Bill 1192 (Choubane and others 1). This bill mandated that the Florida Department of Transportation (FDOT) look into the possibilities that waste tires could bring when mixed with other pavement materials. Unable to incorporate waste tires with 85 percent of their standard pavement production due to the incorporation of reclaimed asphalt (an average of 30 percent per batch), the FDOT considered other mixtures with virgin aggregate that would not hinder the recycling process of the reclaimed asphalt. Blessed with the asphalt rubber studies of other states, FDOT was able to glean from the knowledge of others and produce three
pavement alternatives for testing. Each project was designed with the specific climate and traffic flow of Florida in mind. The studies reviled that the “wet process addition of rubber improved the crack resistance of surface mixtures… [and] an effective optimum rubber content [needs to] be within the 10 to 15 percent range” (Choubane and others 1).

During March of 1992, the *Design Guide for Asphalt Rubber Hot Mix-Gap Graded (ARHM-GG)* became available from Caltrans. The guide was a collection of information, produced from Caltrans’ studies and project reviews, which had been analyzed and formulated into design criteria. The information proved to be so accurate and valuable that, in June of 2001, it was included in the *Caltrans Flexible Pavements Rehabilitation Manuel*. Showing their faith in the ability of RAC, by 1995 there were more than 100 RAC roadway designs carried out by Caltrans. Other planning departments in California’s counties had also included asphalt rubber designs totaling over 500 projects in all.

Even though RAC and other rubberized asphalt projects had become increasingly popular and successful in California, Arizona, Florida, and other states, not every project depicted the perfect picture of durability and longevity. Application of an unfamiliar product proved to be a setback in the success of some projects. Several contractors were inexperienced and lacked a workable knowledge of RAC products, thus causing premature distress of the newly-paved roadway. A lack of guidelines and specifications for rubber asphalt mix binders was also a thorn in the side of success; projects were structurally unsound due to bad batches of RAC (Hicks and Others 2-1). However, after investigation of problematic areas, it was the opinion of Caltrans-Industry that rubberized asphalts can be a benefit to roadway design when proper specifications are used during the design process and if contractors follow recommended application methods.
Composition and Production Process:

The term Rubberized Asphalt Concrete is defined in the *Asphalt Rubber Design and Construction Guidelines, Volume 1*, as a term that “implies the use of an asphalt-rubber blend (binder) with dense-graded aggregates in a hot-mix application” (California DOT viii). Though there are many different mixes of rubber, asphalt, and concrete, the leading mix used by Caltrans in their restoration projects is gap-graded RAC (RAC-G). Gap-Grade Rubberized Asphalt Concrete incorporates “aggregate that is not continuously graded for all size fractions, but is typically missing or low on some of the finer size fractions,” traditional asphalt materials, and a crumb rubber with a diameter of minus 2 millimeters (Caltrans ARUG viii). RAC-G is designed to integrate stone-to-stone interaction to provide structural strength, enabling the roadway to combat “rutting, fatigue and reflective cracking, and… oxidative ageing” (RAC Materials 3-9).

Other grades of RAC are designed to improve specific driving conditions, such as open-grade mixes (RAC-0). This particular type of RAC is formulated to encourage water drainage by allowing water to seep through the surface layer (RAC-O) and drain away. In turn, this design decreases water spray from the rear of moving cars, the likelihood of water puddles causing splashing, and the dangerous possibility of hydroplaning. Other positive effects of using RAC-O on roadway paving projects are the reduction in tire noise and a smoother ride. Even with these great benefits, this type of RAC is unsuited for snowy conditions and stop-and-go traffic; it can also be affected by car fluids (RAC Materials 3-12, 3-13). A dense-grade rubberized asphalt concrete is also used in construction; however, this grade is not used by Caltrans due to its “inadequate void space to accommodate sufficient AR binder to modify [the] mix[s] behavior” (RAC Materials 3-9). Each grade of RAC has its own set of specifications and guidelines to follow in order to have a successful end result; all compositions of RAC must be tested to insure
that proper amounts are used and compatibility among the materials is reached. The wet process in which RAC-G is produced consists of taking traditional asphalt materials with a 7.0 minimum to 9.0 maximum percent by mass of dry aggregate and heating them to 190°C to 224°C (375°F to 435°F) and then adding the mixture to a crumb rubber modifier (CRM) in a high shear blender (Hicks and others viii). The CRM is composed of 73 to 77 percent crumb rubber from scrap tires and 23 to 27 percent from high natural crumb rubber. Caltrans also incorporates extender oil in their mixes to encourage an even distribution of rubber in the mixture. The extender oil works “by providing aromatics which are absorbed by the rubber, and help with dispersion by chemically suspending the rubber in the asphalt” (RAC Materials 3-6). When the mixture has been thoroughly blended, the paving material is then transferred into a rotational reaction vessel where it is allowed to react for a minimum of 45 minutes at 149°C to 163°C [300°F to 325°F] (Hicks and others 4-2). The rotation of the reaction vessel is necessary to insure that the rubber particles are evenly distributed throughout the blend (See Figure 1). The reaction time allows the properties of the asphalt cement to be modified into RAC-G. This happens through a polymer swell where physical properties (oils) of the combined materials
(asphalt cement, CRM, and extender oils) join together, creating the desired result. It is the “CRM gradation and content… [that] influences the voids structure of RAC-G mixes” (RAC Materials 3-4). Other mixes follow a similar production format with different specifications that need to be observed (Caltrans ARUG). This mixing process can take place at any asphalt plant with the simple addition of an agitated tank, blending tank, an extra tank, and a small storage shed to hold the extender oils. An example of some of the equipment needed is featured in the Asphalt-Rubber Blending Site seen above (See Figure 2).

**Application:**

Though rubberized asphalt concrete can be used in new construction, it is primarily used in preventative and corrective roadway maintenance. Different organizations approach their maintenance plans in ways that meet their specific needs and budgets. Some choose to use a thin layer of RAC prior to visual signs of deterioration, thus prolonging the life of the roadway and preventing possible structural problems from affecting the original roadway. Other agencies may not have enough time or resources to prevent problems, so they are bound to fix issues as
they arise. Normal problems that affect a roadway as it ages include: “loss of friction, rutting, cracking, or raveling” (Hicks and others 3-3).

An important factor to consider prior to any RAC application is the climate. Different geographical areas will have diverse seasons during which laying RAC is feasible. It is not advised that any asphalt rubber product be used during temperatures that are below 13°C (55°F) unless special measures are followed to insure proper RAC placement. Disregarding this specification will cause problems during compaction of the RAC, which can lead to premature aging of the roadway surface or even complete roadway failure (Hicks and others 3-3). The reason that these cool exterior temperatures have such an affect on the placement of RAC is due to the fact that RAC-G must be compacted when its temperature is between 134°C to 149°C (290°F to 300°F); cool outside temperatures will quickly lower the temperature of the RAC-G before the compaction process is finished (Hicks and others 4-2).

A thought-out design based on specification and consistency testing is an important foundation for the rubberized asphalt application process. Engineers will design either a two layer or three layer system, depending on the structural damage and original roadway material in order to combat roadway deterioration. To the right is Figure 3, depicting a side profile of a two layer system.

A three layer system (see Figure 4 below) typically starts off by having the existing pavement cracks sealed along with the removal and replacement of any sections of the roadway.
that have undergone severe structural damage. To help insure a smooth surface, a layer of leveling course is placed over the surface of the roadway, making sure that all the ruts have been covered and the resulting profile is acceptable. This leveling course is composed of hot mix asphalt. A stress-absorbing membrane (SAMI) is then placed to “mitigate reflective cracking of an existing distressed asphalt or rigid pavement” along with helping the RAC bond properly to the existing roadway (Hisks and others ix). This layer typically consists of a spray application of asphalt rubber and cover aggregate; however, other types of SAMI can be “fabric, fine unbound aggregate, or an open-grade asphalt layer” (Hicks and others ix). Next comes a layer of rubberized asphalt concrete to act as the topcoat and roadway surface.

The first step in a successful RAC application is the delivery. Any standard transportation truck used for traditional hot mix asphalts can be used. Placing an insulation tarp over the top of the RAC hot mix is required to insure that proper application temperatures are maintained. It is important to watch for visual signs that might indicate a problem with the RAC upon delivery, such as the following: blue smoke (overheated mix), stiff appearance (cool mix), slumped mix (excess asphalt rubber binder or moisture), dull appearance (not enough asphalt rubber binder), or rising steam (excess moisture) (Hicks and others 5-2).
Prior to the RAC application, any debris on the roadway area should be removed before the RAC is applied. The surface also needs to be dry to guarantee for proper application. Once the road is ready, a new topcoat of RAC is then laid, providing the existing roadway with a much needed layer of reinforcement. The RAC being placed “must be a free flowing, homogeneous mass in which there is no segregation, crusts lumps, or migration of the asphalt rubber” (Hicks and others 5-3). This will allow for proper compaction to 5 to 8 percent air void (Hicks and others 5-3). It is important when working with RAC to attempt to lay the RAC in a manner that, when finished, will leave little or no raking necessary. RAC’s consistency and its cooling factor greatly inhibit manual maneuvering of it. The lift thickness will vary from project to project; however, the standard requirement for calculating the proper lift thickness is “2 to 3 times the maximum aggregate size” (Hicks and others 5-3). Sand can be applied in small amounts on the newly paved roadway to help reduce the chances of traveling vehicles picking up pieces of the RAC. This completes the rubberized asphalt application through the three layer system.

Environmental Benefits:

As previously stated, rubberized asphalt concrete is partly composed of crumb rubber derived from waste tires. The definition of waste tire is “a tire that is no longer mounted on a vehicle and is no longer suitable for use as a vehicle tire due to wear, damage, or deviation from the manufacture’s original specifications” (CIWMB 1). There are specific guidelines to follow when classifying a tire, which can be found in California’s Public Resources Code 30. According to the California Tire Management website, California produces over 40.2 million tires a year that must be sold on the used tire market or disposed of if unable to be reused. In addition, they have estimated the number of tires that “have been illegally dumped or stockpiled” to be a stunning 1.5 million (Tire Management 1). The United States Environmental Protection
Agency reported that the United States as a whole produced 290 million used tires in 2003. They also state that 80.4 percent (233 million) of these waste tires were being reused for non-vehicle needs or recycled as fuel or in engineering projects (see Table 1 below). Even with progress in the proper disposal of waste tires, the problem of inappropriate dumping and storage of waste tires still exists and imposes health risks on the public (US EPA 1).

Table 1: 2003 Markets for Scrap Tires, information provided by the United States Environmental Protection Agency, Table created by Israel Patterson

<table>
<thead>
<tr>
<th>Types of Uses</th>
<th>% Used in Projects</th>
<th>Number of Tires Used in Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used as Fuel</td>
<td>44.7%</td>
<td>130 Million</td>
</tr>
<tr>
<td>Recycled or Used in Civil Engineering Projects</td>
<td>19.4%</td>
<td>55 Million</td>
</tr>
<tr>
<td>Converted into Ground Rubber and Recycled into Products</td>
<td>7.8%</td>
<td>18 Million</td>
</tr>
<tr>
<td>Converted into Ground Rubber and Used into Rubber-Modified Asphalt</td>
<td>4.3%</td>
<td>12 Million</td>
</tr>
<tr>
<td>Exported to Foreign Countries to be Reused as Retreads</td>
<td>3.1%</td>
<td>9 Million</td>
</tr>
<tr>
<td>Recycled into Cut/Stamped/Punched Products</td>
<td>2.0%</td>
<td>6.5 Million</td>
</tr>
<tr>
<td>Used in Agricultural and Miscellaneous Uses</td>
<td>1.7%</td>
<td>3 Million</td>
</tr>
</tbody>
</table>

There are three major health issues involved when tires are illegally dumped or stockpiled which are the following: providing an ideal environment for rodent breeding; allowing rainwater to collect, thus enabling an aquatic environment for mosquito larva; and a potential fire risk that if ignited would produce toxic smoke containing CO, SO₂, NO₂, and HCl (US EPA 3/Problems About Waste Tires 2). One example of a toxic and environmentally damaging tire fire was in 1983 when Virginia was plagued with a nine month long, 7 million tire-burning fire. The number of tires posing a health threat in 1994 was 700 to 800 million. However, by 2004, the number of tires was estimated to be down to 275 million. This drastic change was credited “to aggressive cleanup through state scrape tire management programs” (US EPA 2).

Just less than one quarter of all waste tires which are not reused or recycled or are disposed of properly find their way to landfills. Tires pose a threat to the success of landfills due to their uncanny ability to rise to the surface and their addition of a large amount of bulk to the landfill. Even with the known hazards that scrap tires bring to landfills, as of 2003, there were
still eight states that had not established guidelines or restrictions in regards to tires entering landfills (US EPA 2).

Recycling waste tires for the purpose of creating RAC has proven to be a leading factor in the reduction of waste tires. The ability to reduce health hazards posed by stored waste tires and the reduced size of landfills are both great environmental benefits that RAC helps bring about. However, the question remains: does using rubber in these new forms (such as RAC) cause harm to the environment? The main areas that have been investigated to insure that no environmental harm is being done during the RAC process are: air pollution during the mixing process and the application procedure.

According to an article written by Jack Van Kirk, a Senior Materials and Research Engineering with Caltrans, due to health complaints voiced by construction workers who work within close proximity to RAC, studies have been conducted to insure that all health requirements are being met. Through the results of over fifteen air quality studies Caltrans determined “that employee exposures during paving are below CalOSHA allowable limits” (Kirk 6). Even though all standards were being met, RAC mix temperatures were lowered to help reduce the possibility of asphalt fumes being inhaled by the workers. However, Caltrans received additional complaints, and even though the CalOSHA limits were not exceeded, Caltrans is going to continue their investigation to insure that the best possible health standards are followed.

During the mixing process at the asphalt plant, standard practices are followed to reduce the amount of smoke and fumes that are being expelled into the air. In general, most asphalt plants are required to obtain air quality permits and provide documentation that the asphalt plant is not exceeding the allowable amount of smoke and fumes. The two most effective ways to
reduce the resulting pollutants are to “produce the mix at the lowest possible temperature” and to “ensure the flights in drum plants are in good working order” (Hicks and others 5-2). There have been extensive studies conducted on both air quality at the mixing locations and air quality at the application site, and even though there has yet to be any indications that RAC mixtures are more hazardous than other paving asphalts mixtures, most studies conclude by recommending that workers reduce the amount of exposure to any RAC smoke or fumes as much as possible. Overall, the environmental benefits that rubberized asphalt concrete offers far outweigh the inconveniences of taking extra precaution while working around this valuable product.

**Future of Rubberized Asphalt Concrete:**

In October 2005, a mandate was set forth and signed by Governor Arnold Scharzenegger to encourage the use of RAC. The law (AB338) was to become active on January 1, 2007, thus requiring Caltrans to increase their use of RAC to meet the required amounts of RAC usage set forth in the mandate (see Table 2). This would bring the percent of RAC compared to the total production of asphalt concrete from 20 percent in 2005 up to 35 percent by 2013 (Carlson 1/ Introduction RAC Pilot Training Course 1-3). Starting this mandated increase out on the right foot, Caltrans was awarded a RAC-G restoration project of 116 lane miles for the Angles Forest Highway. Just this single project would use more than 122,000 metric tones of RAC-G, consuming more then 360,000 waste tires generated from California drivers (Carlson 1-2).

The cost of RAC products compared to that of standard asphalt concrete requires a larger amount of monetary investment. However, because of the extended life cycle of RAC along

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount of RAC in pounds/total tons of asphalt paving materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>6.62</td>
</tr>
<tr>
<td>2010</td>
<td>8.72</td>
</tr>
<tr>
<td>2013</td>
<td>11.58</td>
</tr>
</tbody>
</table>
with the fact that RAC can be laid in thinner applications, the initial cost evens out in the end. According to the study *Life cycle costs for asphalt-rubber paving materials* conducted by R.G. Hicks and Jon A. Epps, RAC “is a cost-effective solution in most of the scenarios evaluated” (Hicks and Epps 21). They did make the statement that if at least one of the following two things did not occur, then RAC would not be cost effective: “thickness of the layer is reduced or extended life is achieved” (Hicks and Epps 21).

Education of engineers and future engineers in the environmental and design benefits that rubberized asphalt concrete has to offer is the key to the successful increase of RAC in pavement applications. The California Integrated Waste Management Board (CIWMB) is in the trenches working towards the education of RAC and other civil engineering applications that would drastically reduce the amount of waste tires that California is producing each year. If engineers chose to design projects with material that not only accomplishes the task but also improves the environment, RAC will grow in popularity and the general population and environment will reap the benefits. The main benefits of RAC that help encourage its future use are:

- Good durability – in terms of resistance to cracking and aging.
- Environmentally friendly – makes value-added use of a waste material, reduces traffic noise.
- Versatility – can be used in most maintenance and rehabilitation activities or in reduced thickness for resistance to reflective cracking.
- Longer lasting color – for better contrast with striping and marking.
- Reduced maintenance – for both chip seals and hot mix. (PRIR 1-6)

Some issues that need to be considered prior to making the decision to use RAC in a project design are: what will the mobilization costs be; whether the project is so small that the higher unit price may not be fully offset by the positive aspects of RAC; and whether the construction crews have knowledge and experience with RAC, (if they are not familiar with the
temperature requirements and the decreased ability to hand manipulate RAC, problems could arise). With the numerous benefits of RAC in mind, watching for potential problems that might arise, a proper design, and following specified construction requirement will make the use of RAC will be successful and a positive experience.

As the history of rubberized asphalt concrete has unfolded, RAC has become a integral part of roadway rehabilitation. Through case studies, cost evaluations, and laboratory mixing studies, design and application specifications have been developed to insure the successful outcome of projects utilizing RAC. RAC not only produces a nice-looking roadway with a smoother driving surface when compared to that of conventional asphalt, but it also encourages the movement towards a healthier environment by using waste tires in its composition. Rubberized asphalt concrete has shown itself to be a reliable resource in roadway construction; as people move towards a more environmentally aware society and learn about the multiple benefits RAC has to offer, it is very likely that the usage of RAC will only continue to grow.
Works Cited


Hicks, R.G. “Life cycle costs for asphalt-rubber paving materials.” 5 Dec. 2007 <
www.ecst.csuchico.edu/~dxcheng/CE_Application_Resources/Asphalt-Rubber%
20Information%20Index%20Page.mht>.

North Carolina Department of Environmental and Natural Resources, “Environmental Problem
Associated with Waste Tires.” North Carolina Department of Environmental and Natural
problems.htm>.

10 Nov. 2007 < http://www.ecst.csuchico.edu/~dxcheng/Index%20of%20CIWMB%20
Tire%20as%20Building%20Material%20Outreach%20Research.htm>.


Information. 2000. 23 November 2007 <http://www.ecst.csuchico.edu/~dxcheng
/CE_Application_Resources/Asphalt-Rubber%20Information%20Index%20Page.mht>.

State of California Department of Transportation. “Asphalt Rubber Usage Guide.” State of
dot.ca.gov/hq/esc/Translab/pubs/Caltrans_Ashphalt_Rubber_Usage_Guide.pdf >.

Van Kirk, Jack. “Caltrans Pavement Rehabilitation Using Rubberized Asphalt Concrete.”
California Department of Transportation. May 1997. 29 Nov. 2007 <www.asphaltrubber
.org/RPA_Newsletters/May97/caltrans.html>.

Preservation Concurrence. April 2006. 20 Nov. 2007 <www.techtransfer.berkeley.edu/
pavementpres06downloads/vankirk2.pdf>.
