USE OF CRUMB RUBBER ADDITIVES

IN

REGION 10

by

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INTRODUCTION

The use of crumb rubber additives (CRA) in hot mix asphalt concrete pavement has recently been receiving a great deal of national attention. It is being considered by some as the solution to our nation's waste tire stockpile problem. Our environment and health are being jeopardized by this problem which is growing at an alarming rate. The Environmental Protection Agency (EPA) estimates that 2-1/2 to 3 billion tires are currently stockpiled and 280 million tires are wasted each year. Of these 280 million tires, approximately 85 percent will be added to stockpiles and only 15% will be recovered by recycling or by energy recovery. To solve our nation's stockpile problem, recycling of waste tires needs to increase. (1)

When awareness of our stockpile problem increased, agencies began searching for solutions to the problem. The Federal Highway Administration (FHWA) began evaluating the use of scrap tires as a potential additive for asphalt paving products with Demonstration Project No. 37 "The Use of Discarded Tires in Highway Construction" in 1976. Over 40 projects using asphalt-rubber binder as a pavement surface treatments were evaluated. In 1983, FHWA initiated Demonstration Project No. 3 "Asphalt Additives" which has been evaluating asphalt-rubber and rubber-modified hot mix asphalt concrete paving products. On April 18, 1990, Mr. Douglas Bernard, FHWA Demonstration Projects Division Chief, expressed FHWA's position on the use of CRA in asphalt pavements during his testimony to the House Committee on Small Business for the scrap tire management and recycling opportunities hearing. He testified (Appendix A) that FHWA was encouraging and monitoring State conducted evaluations of CRA use in asphalt pavements.

States also began searching for solutions to their local waste tire stockpile problems. Many states are proposing waste tire disposal regulations (Table 1) (2)(3). Research on the use of CRA in asphalt pavements was initiated by some states while other states passed legislation encouraging and/or mandating the use of waste tires in asphalt pavements. New York has already mandated the use of waste tires in asphalt pavements with similar legislation currently being proposed in Rhode Island and Florida. Legislation was passed in 1989 requiring the California Department of Transportation to modify their asphalt pavement specification to increase waste tire usage. Other state highway agencies (Maine, Minnesota, New Jersey, Oregon, Tennessee, and Virginia) are being asked by their legislators to investigate the use of waste tires in their pavement (2).
TABLE 1 - STATES WITH PROPOSED WASTE TIRE DISPOSAL REGULATIONS

Alaska  Nebraska
Arizona  New Hampshire
California  New Jersey
Connecticut  Ohio
Iowa  Oklahoma
Illinois  Oregon
Kansas  Pennsylvania
Kentucky  Rhode Island
Massachusetts  South Carolina
Maine  Tennessee
Maryland  Texas
Michigan  Vermont
Minnesota  Virginia
Mississippi  West Virginia
Missouri  Wyoming

HISTORY OF CRUMB RUBBER ADDITIVES

Adding crumb rubber to asphalt was first experimented with by Charles H. McDonald of the City of Phoenix in 1963 (4). He reactively added crumb rubber and asphalt to modify certain characteristics of the asphalt. The addition of rubber produced a tough and viscous modified asphalt (asphalt-rubber) that resisted reflective cracking (5).

McDonald's asphalt-rubber was first used as a surface treatment in 1964 by the Arizona Department of Transportation (5). A patent was issued to U.S. Rubber Reclaiming Company for the following asphalt-rubber surface treatments: Stress Absorbing Membranes (SAM), Stress Absorbing Membrane Interlayer (SAMI), seal coats, and crack sealing (6). In 1975, the Arizona Department of Transportation was the first to use asphalt-rubber as the binder in a hot asphalt mix (5). A patent was issued on this asphalt rubber binder system called Arm-R-Shield™ to U.S. Rubber Reclaiming Company (4).

In 1969, a different process of adding crumb rubber to asphalt was developed in Sweden (1). Coarse rubber particles were added to a hot asphalt mix as replacement aggregates to increase flexibility and durability (7). This rubber-modified asphalt pavement was patented in Sweden as Rubit™. In the late 1970's, All Seasons Surfacing Corporation patented this process in the U.S. as PlusRide™ (4). It was believed with elastic aggregates in the pavement, the skid resistance increased, noise was reduced, and light reflection was minimized (4). The rubber-modified asphalt pavement was reported to have deicing capabilities under traffic and an increased fatigue life due to the increased elasticity of the pavement (1).
In 1989, Dr. Hossein Takallou began developing another application of the rubber-modified CRA process. In response to the increasing concerns over our nation's waste tire stockpile problem, CRA processes were being investigated as possible solutions to the problem. The two existing processes had the potential to help solve this problem but were not considered economically viable solutions because of their high cost due to their proprietary nature (4). Dr. Takallou began developing a non-proprietary "generic" rubber-modified asphalt CRA process that combined the beneficial aspects of both the asphalt-rubber and the rubber-modified processes without the high proprietary cost. As part of its development, the "generic" process was used on two projects in New York in 1989.

The "generic" CRA process is still being developed. In Oregon, the Portland Metropolitan Service District (METRO) and the Department of Environmental Quality (DEQ) are working together with TAK Associates (Dr. Hossein Takallou) to develop and evaluate a "generic" rubber-modified asphalt concrete pavement with their DEQ/METRO Rubber-Modified Asphalt Concrete Paving Demonstration Project. The completed development of the "generic" CRA process is expected to encourage competitive bidding through the use of a non-proprietary process, to minimize the impact on a contractor's operations, to promote the use of crumb rubber in asphalt mixes, and to increase the cost effectiveness of CRA asphalt pavements.

CRUMB RUBBER ADDITIVE PROCESSES

Crumb Rubber Asphalt Terminology

With the rapid technological evolution of CRA, the terminology used to describe the CRA processes has not been clearly defined. The following defines some of the commonly used CRA terminology.

Vulcanized Rubber - Natural rubber that has been modified with sulfur or other chemicals to reduce temperature susceptibility making the rubber tough, non-tacky, and resistant to deformation (4).

De-vulcanized Rubber - Vulcanized rubber that is treated with heat, pressure, and softening agents to break the chemical bonds of vulcanization (4).

Ground Rubber - Rubber particles that are "torn" into irregular shapes using a cracker mill grinding process. Ambient conditions are used. The asphalt-rubber CRA process typically uses ground vulcanized rubber.

Granulated Rubber - Rubber particles that are "sheared" into cubical shapes using a granulator. Ambient conditions are used. The rubber-modified CRA process typically uses granulated vulcanized rubber.
Crumb Rubber - Ground or granulated rubber particles.

Crumb Rubber Additive (CRA) - Generic term for crumb rubber used in asphalt paving applications.

Ambient Grinding - Grinding under ambient temperature conditions. The rubber particles produced are irregularly shaped with torn edges.

Ambient Granulated - Granulated under ambient temperature conditions. The rubber particles produced are cut smooth with sharp, angular edges.

"Wet" CRA Process - The crumb rubber particles are reactively added to the asphalt binder of an asphalt mix. Also referred to as the reactive CRA process or the asphalt-rubber CRA process.

"Dry" CRA Process - The crumb rubber particles are used as elastic replacement aggregates in an asphalt mix. Also referred to as the non-reactive process or the rubber-modified CRA process.

Rubber Characteristics

Each of the CRA processes integrates rubber into the asphalt mix differently to modify certain characteristics of the asphalt pavement (1). The asphalt-rubber process ("wet" process) reacts the rubber with the asphalt binder, and the rubber-modified process ("dry" process) uses the rubber as an elastic aggregate. The "generic" rubber-modified process primarily uses the rubber as an elastic aggregate but a portion of the rubber reacts with the asphalt binder. The result is a semi-"wet" CRA process. The ability of each CRA process to modify certain characteristics of an asphalt pavement is largely a result of the characteristics of the rubber particles and the degree of reaction between the rubber and asphalt (4).

The shape, size, and morphology (structure) of the rubber particles effect the characteristics of a CRA asphalt pavement. Torn, irregularly shaped particles have more surface area for the asphalt binder to react with increasing the viscosity and elastic recovery. Small particles tend to swell and disperse better in the asphalt binder which increases the viscosity and elastic recovery. The asphalt mix also requires less of an increase in the asphalt binder content. Large rubber particles require more of an increase in the asphalt binder content and act as elastic aggregates which increase the crack resistance and mix toughness. (4)

In the early research with CRA, vulcanized and devulcanized rubber particles were thought to have an effect on the characteristics of a CRA asphalt pavement. The asphalt-rubber process used devulcanized rubber which was more reactive in asphalt (4). The rubber-modified process used vulcanized rubber which was less reactive in asphalt (4). There was no conclusive evidence that one
was better than the other so the less expensive vulcanized crumb rubber was used. All three processes now specify vulcanized crumb rubber, but devulcanized rubber is sometimes added to modify certain characteristics of an asphalt pavement.

**Asphalt-Rubber**

The asphalt-rubber CRA process can be used for an open, dense, or gap-graded asphalt concrete pavement. Three types of asphalt-rubber binders are specified for different environmental conditions: Type I, low stiffness for cold climates; Type II, moderate stiffness for moderate climates; and Type III, high stiffness for hot climates (4). The process uses 10 to 25 percent crumb rubber by weight of the total binder. It is ground to the minus #10 sieve. The ground rubber is added to the asphalt and reactively mixed at an elevated temperature of 350°F ±10°F for 60 minutes. Special blending equipment and storage tanks for mixing the rubber with the asphalt are required (1). To meet the manufacturers asphalt-rubber binder specifications, extender oils are sometimes necessary. The "International Surfacing, Inc., Guide Specifications for Open, Dense, and Gap-Graded Asphalt Concrete Pavements with Asphalt-Rubber Binder" are contained in Appendix B.

Asphalt-rubber pavement is placed using conventional paving equipment. Compaction must be done using steel-wheel type rollers since the asphalt mix has a tendency to stick to pneumatic-wheel type rollers. Obtaining the required voids is essential to the performance of the pavement. Compared to conventional asphalt, additional compaction effort is required with asphalt-rubber pavement to obtain the required voids (6).

After asphalt-rubber concrete pavement is placed, it typically looks like a "rich" conventional asphalt concrete pavement. When the pavement surface begins to wear from traffic loading, it is not distinguishable from a conventional asphalt concrete pavement (Photo #1).

Asphalt-rubber pavement was developed primarily to overcome the problem of early reflection of fatigue cracks on resurfaced pavements (4). Characteristics of asphalt-rubber pavement are affected by the physical and chemical properties of the asphalt, the type of rubber, the mixing time and temperature, the mixing conditions (high or low shear mixing), and the use of other additives. It is promoted as having more flexibility, slower aging, less raveling, extended construction season, and more resistance to rutting and shoving (6). Reported benefits are improved resistance to cracking, rutting, and aging (1). This CRA process is more expensive than conventional asphalt due to its proprietary nature, but it is promoted that only half the thickness of a conventional asphalt overlay is necessary.
Rubber-Modified Asphalt

The rubber-modified CRA process is a gap-graded asphalt concrete pavement. Typically, the less reactive vulcanized rubber is used for the crumb rubber which is a blend of coarse (granulated) and fine (milled) particles (4). The process uses a maximum of 3 percent crumb rubber by weight of the total mixture (4). A batch plant is preferred for the production of rubber-modified asphalt because the quantity control of the materials is better. The crumb rubber is added typically in 60 lb. sacks directly into the drum mixer (Photo #2) where it is mixed with the aggregates for approximately 30 seconds. The total batch plant mixing time is approximately 60 seconds (8).

Rubber-modified asphalt pavement is placed using conventional paving equipment (Photo #3). Compaction must be done using steel-wheel type rollers since the asphalt mix has a tendency to stick to pneumatic-wheel type rollers. Obtaining the required voids is essential to the performance of the pavement. Compared to conventional asphalt, additional compaction effort is required with rubber-modified asphalt pavement to obtain the required voids (6).
Photo #2 - In a batch plant production of rubber-modified asphalt concrete mix, crumb rubber is added typically in 60 lb. sacks directly into the drum mixer. (Morse Brothers Construction, Benton County, Oregon, J. Trunk, 9/21/90)

Photo #3 - Rubber-modified asphalt concrete pavement is placed using conventional asphalt paving equipment. (Alpine Cutoff Road, Benton County, Oregon, J. Trunk, 9/21/90)
After rubber-modified asphalt concrete pavement is placed, it typically looks like a "rich" conventional asphalt pavement (Photo #4). The rubber particles are not visibly apparent in the pavement. When the pavement begins to wear from traffic loading, the rubber particles become visible making it distinguishable from a conventional asphalt concrete pavement (Photo #5). This is typical of rubber-modified asphalt concrete pavement.

Rubber-modified asphalt pavement is promoted to improve skid resistance, fatigue resistance, and have deicing capabilities. It is believed deicing results when the coarse rubber particles flex under traffic breaking up the ice deposits (2). Some reported benefits from rubber-modified asphalt pavement are improved safety and crack resistance (1). It has also been reported to have an increased fatigue life, reduced noise, and controlled reflective cracking (7). The required gap-grading of the aggregates for the rubber-modified process is reported by some to have caused quality control problems during production. This process is more expensive than conventional asphalt due to its proprietary nature, but it is promoted that only half the thickness of a conventional asphalt overlay is necessary.

Photo #4 - The rubber particles in rubber-modified asphalt concrete pavement are not visible immediately after placement. (Alpine Cutoff Road, Benton County, Oregon, J. Trunk, 9/21/90)
"Generic" Rubber-Modified Asphalt

The "generic" rubber-modified CRA process is another "dry" process but the resulting product is semi-"wet". This process is still being developed. It is anticipated that the benefits from both the "wet" and the "dry" processes will be combined in this "generic" process with increased product quality control and constructability all at a lower cost. The draft specification for this process that is being developed for use in Oregon is contained in Appendix C.
CASE STUDIES IN REGION 10

Asphalt-Rubber Process

The asphalt-rubber CRA process was used in two of the four states in Region 10. These projects are listed in Tables 2 and 3, and discussed in further detail below.

♦ Alaska

There was no record of asphalt-rubber concrete pavement being used in Alaska.

♦ Idaho

There was no record of asphalt-rubber concrete pavement being used in Idaho. International Surfacing, Inc. thought one project had been done in the State, but the pavement performance was unsuccessful.

♦ Oregon

In 1985, the Oregon Department of Transportation constructed a 3.87 mile asphalt concrete test strip approximately 20 miles south of Bend on U.S. 97. This test strip was constructed to evaluate the construction and performance of 8 different hot mix asphalt additives. The test strip contained two control sections of Oregon's Class C asphalt, one with and one without lime. One of the asphalt additive test sections was an 0.8 mile length of asphalt-rubber concrete pavement, north and south bound main lanes. (9)

The first three years of the evaluation only laboratory testing was done. The fourth year, laboratory testing and visual surveys were done. (9) Pavement distresses were not visibly apparent until the fifth year survey. The two control test sections were beginning to fail. Hairline map or fatigue cracking was visible in the wheel path (Photo #6). Transverse cracking was also visible (Photo #7). The asphalt-rubber concrete pavement test section was performing the best after five years, slightly better than the control test sections. There was no map or fatigue wheel path cracking visible (Photo #8) and only half of the test section had hairline transverse cracking. (10)

From the laboratory testing, the State determined that some conventional asphalt tests did not provide reliable performance indicators for CRA asphalt products. During the binder tests (extraction), a great deal of the rubber was also removed. Consequently, penetration and viscosity test results were not considered accurate performance indicators. The results of the fatigue testing have not been determine as of yet. (10)
In 1984, Linn County resurfaced 3.9 miles of north Brewster Road with 1" of asphalt-rubber concrete pavement. An asphalt-rubber interlayer was also used. The asphalt-rubber mix had an asphalt content of 7.3 percent and cost $52.66 per ton. The volume of traffic on this section of Brewster Road was 2300 ADT. Two years later, 2.9 miles of south Brewster Road was overlaid with 1" of asphalt-rubber pavement. This section of Brewster Road had an ADT of 2,500. The asphalt-rubber mix had an asphalt content of 7.3 percent and cost $57.65 per ton. The pavement has been performing well on both sections of Brewster Road. (11)

In 1985, Linn Country resurfaced 2.6 miles Old Salem Road with 1" of asphalt-rubber concrete pavement. The volume of traffic on this section of Old Salem Road was predicted at 3,500 ADT. The asphalt-rubber mix had an asphalt content of 6.7 percent and cost $57.65 per ton. Five years later, a different section of Old Salem Road was overlaid with 1.5" of asphalt-rubber concrete pavement. This section was 1.5 miles in length and had an ADT of 5000. The asphalt-rubber mix had an asphalt content of 8 percent and cost $48.64 per ton. To date, the pavement has been performing well on both sections of Old Salem Road with no distresses visibly apparent. (11)

In 1989, Jackson County paved 3 miles of Mill Creek Drive near the City of Prospect with 1.5" of asphalt-rubber concrete pavement. The environmental conditions in this remote area are severe with freeze/thaw and ice/snow. The overlay was designed for the predicted traffic volumes of 500 ADT. The existing road was severely rutted so a leveling course of Oregon's Class C asphalt was used. Half of the project was rehabilitated before the leveling course was placed. (12)

The County was "pleasantly surprised" during and after the placement of the asphalt-rubber pavement. The overlay went down good with no problems encountered. They had specified in the project contract that the distributor, International Surfacing, Inc., would provide technical assistance throughout the duration of the project. The County felt that this technical assistance contributed greatly to the success of the project. The asphalt-rubber mix design is contained in Appendix D. (12)

The County had been considering using asphalt-rubber concrete pavement on a project for two or three years but the cost was considerably more expensive than conventional asphalt, approximately 40 to 50 percent more. They were able to reduce the in-place cost by reducing the conventional asphalt overlay thickness of 3" to an asphalt-rubber overlay thickness of 1.5". They also felt that the in-place cost was as low as possible because the low bidder, a Portland based contractor, was already set up for production in this remote area. The County estimated that the final in-place cost of the asphalt-rubber pavement was 10 percent more than a conventional asphalt pavement. (12)
The asphalt-rubber pavement is performing well with no oxidation or distresses visibly apparent. The County is currently looking at using this CRA process again on a larger project. (12)

Washington

In 1986, the Washington Department of Transportation overlayed a 2.14 mile section of Interstate 5 in Vancouver with 0.75" of an open-graded asphalt-rubber concrete pavement. The asphalt-rubber overlay was placed in the center lane with and without a fog seal; the southbound lane and 1.71 miles of the northbound lane did not have fog seal; 0.45 miles of the northbound lane had fog seal. The fog seal consisted of CSS-1 applied at a rate of 0.05 to 0.10 (0.03 to 0.05 residual) gallons per square yard. A 1,200 foot control section of conventional asphalt, and a 3,300 foot section of polymer-asphalt were placed on the southbound outer lane. (13)

The State's objective in constructing this experimental pavement section was to find a pavement that had a greater resistance to raveling. There has been only small areas (2 to 3 inches long) in the wheel path that are raveling in all the test sections. The asphalt-rubber concrete pavement has been performing well under the high traffic volumes of Interstate 5. (13)

In 1990, the City of Spokane paved NW Boulevard with asphalt-rubber concrete pavement. The mix used 16 percent crumb rubber by total weight of asphalt-rubber binder. Appendix E contains the Marshall design for the mix. The asphalt-rubber concrete pavement went down well with no compaction problems encountered. (14)

**TABLE 2 - ASPHALT RUBBER PROJECTS IN OREGON**

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>AGENCY</th>
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<tbody>
<tr>
<td>1984</td>
<td>Brewster Rd., North</td>
<td>Linn County</td>
</tr>
<tr>
<td>1985</td>
<td>Hwy 97, Bend area</td>
<td>Oregon DOT</td>
</tr>
<tr>
<td>1985</td>
<td>Old Salem Rd.</td>
<td>Linn County</td>
</tr>
<tr>
<td>1986</td>
<td>Brewster Rd., South</td>
<td>Linn County</td>
</tr>
<tr>
<td>1989</td>
<td>Mill Creek Dr., Prospect area</td>
<td>Jackson County</td>
</tr>
<tr>
<td>1990</td>
<td>Old Salem Rd.</td>
<td>Linn County</td>
</tr>
</tbody>
</table>

Information supplied by Agency and/or Distributor (International Surfacing, Inc., Chandler, Arizona, September 25, 1990)
Photo #6 - The Oregon Class C asphalt with lime on U.S. 97 south of Bend had map or fatigue cracking in the wheel path after five years. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)

Photo #7 - Transverse cracking was also visible in the Oregon Class C asphalt with lime. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)
Photo #8 - The asphalt-rubber concrete pavement had no mat or fatigue cracking in the wheel path and only half of the test section had hairline transverse cracking. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>AGENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>I-5, Vancouver</td>
<td>Washington DOT</td>
</tr>
<tr>
<td>1990</td>
<td>Hwy 195, Pullman area</td>
<td>Washington DOT</td>
</tr>
<tr>
<td>1990</td>
<td>NW Boulevard</td>
<td>City of Spokane</td>
</tr>
</tbody>
</table>

Information supplied by Agency and/or Distributor (International Surfacing, Inc., Chandler, Arizona, September 25, 1990)
Rubber-Modified Asphalt Process

The rubber-modified CRA process was used in three of the four states in Region 10. These projects are listed in Tables 4, 5, and 6, and discussed in further detail below.

- **Alaska**

  Lemon Road near Juneau, was resurfaced with 1.5" of rubber-modified asphalt concrete pavement in 1983. A dryer drum asphalt plant was used to produce the mix. The crumb rubber was added through one of the cold feed bins and then fed into the dryer drum plant along with the mineral aggregate. (16)

  Problems were encountered during the production of the rubber-modified asphalt concrete pavement. The target aggregate gradation (gap-graded) was difficult to produce. Air quality problems were also encountered. Experiments were done with the mixing temperature to reduce the plant's unacceptable emissions. The temperature was reduced from 305°F to 240°F before the emissions were deemed acceptable. The State felt that the air quality problems would not of been encountered if a batch plant had been used. (16)

  In 1986, the Alaska Department of Transportation and Public Facilities (DOT&PF) resurfaced Minnesota Drive Extension in Anchorage with 2" of rubber-modified asphalt concrete pavement placed over insulation board. A control section of conventional asphalt concrete pavement over insulation board was also placed. The State was looking for a friction surface course that would perform well in severe climates. FHWA and Alaska DOT&PF had already determined that an open-graded asphalt friction course was not suitable for use in Alaska. (15)

  The rubber-modified asphalt concrete was produced in a dryer drum plant. Problems were encountered achieving the proper gradation curve and rubber content of 2.5 percent by weight of the total mix. Problems were also encountered with the oil content being too high. Extractions performed after placement of the overlay, verified these two problems. The State felt that a batch plant could of produced a better quality mix without the quantity control problems. (15)

  Placement of the rubber-modified asphalt concrete pavement went smoothly with few problems encountered. Bleeding and tenderness of the mix was controlled by reducing the asphalt content. Problems were encountered with the rubber-modified asphalt mix sticking to the roller. This problem was corrected by delaying the rolling operation until the mat had cooled down to 250°F. (15)

  The State evaluated the resistance and durability of the rubber-modified asphalt concrete pavement for 2 years. A
Tapley meter was used to measure the stopping distances on both the rubber-modified and conventional asphalt pavement test sections. The results were inconclusive due to the wide fluctuation in the measures on both test sections. The durability of the rubber-modified asphalt concrete pavement was good. No raveling had occurred after two years and the pavement had a smooth and quiet ride. (15)

### TABLE 4 - RUBBER-MODIFIED ASPHALT PROJECTS IN ALASKA

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>AGENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>Lemon Road, Juneau</td>
<td>DOT&amp;PF</td>
</tr>
<tr>
<td>1986</td>
<td>Minnesota Drive Extension, Anchorage</td>
<td>DOT&amp;PF</td>
</tr>
</tbody>
</table>

Information supplied by Agency and/or Manufacturer (PAVETECH Corp., Seattle, Washington)

- **Idaho**

  There was no record of rubber-modified asphalt concrete pavement being used in Idaho.

- **Oregon**

  In 1985, the Oregon Department of Transportation constructed a 3.87 mile asphalt concrete test strip approximately 20 miles south of Bend on U.S. 97. This test strip was constructed to evaluate the constructability and performance of 8 different hot mix asphalt additives. The test strip contained two control sections of Oregon's Class C asphalt, one with and one without lime. One of the asphalt additive test sections was an 0.5 mile length of rubber-modified asphalt concrete pavement, north and south bound main lanes. (9)

  The first three years of the evaluation only laboratory testing was done. The fourth year, laboratory testing and visual surveys were done. (9) Pavement distresses were not visibly apparent until the fifth year survey. The two control test sections were beginning to fail. Hairline map or fatigue cracking was visible in the wheel path (Photo #6). Transverse cracking was also visible (Photo #7). The rubber-modified asphalt concrete pavement test section was also showing some distress. The north bound lane had light map and wheel path cracking (Photo #9). Raveling was also getting bad (Photos #10 and #11). After examining the construction records, the distresses were thought to be a result of inadequate compaction of the northbound lane. There was only one transverse crack across both lanes at the northern end of the...
test section (Photo #12). The rubber-modified asphalt concrete pavement did have good resistance to transverse cracking. (10)

Photo #9 - The northbound lane of the rubber-modified asphalt concrete pavement had light map and wheel path cracking. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)
Photo #10 - Raveling was also getting bad in the northbound lane of the rubber-modified asphalt concrete pavement. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)

Photo #11 - Raveling of the northbound rubber-modified asphalt concrete pavement. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)
There was only one transverse crack in the rubber-modified asphalt concrete pavement. The mix had good resistance to transverse cracking. (U.S. 97, Bend, Oregon, J. Trunk, 10/17/90)

From the laboratory testing, the State determined that some conventional asphalt tests did not provide reliable performance indicators for CRA asphalt products. During the binder tests (extraction), a great deal of the rubber was also removed. Consequently, penetration and viscosity test results were not considered accurate performance indicators. The results of the fatigue testing have not been determine as of yet. (10)

In 1987, Benton County resurfaced Springhill Drive in north Albany with rubber-modified asphalt concrete pavement. This 1.7 miles of road had transverse, longitudinal, and alligator cracking. The original design call for 3.25" of conventional asphalt, but only 2.75" of the rubber-modified asphalt pavement was used at a cost of approximately $48 per ton. To date, the pavement has been performing well. (17)

One year later, Benton County resurfaced 19th Street with rubber-modified asphalt concrete pavement. The original design called for 6" of conventional asphalt pavement but with
the rubber-modified asphalt pavement the thickness was reduced to 3". Resurfacing was done in two phases: 1500 tons at a cost of approximately $48 per ton, and 1542 tons at a cost of approximately $49.80 per ton. Again, the pavement is performing well with no distresses visibly apparent. (17)

In 1990, Benton County resurfaced 0.84 miles of Alpine Cutoff Road and 1.5 miles of Evergreen Road with rubber-modified asphalt concrete pavement. Both of these paving projects were accepted as DEQ/METRO Rubber-Modified Asphalt Concrete Paving Demonstration Projects. In conjunction with being demonstration projects, air opacity measurements were made at the asphalt batch plant and determined acceptable by DEQ Air Quality personnel. Both projects used the rubber-modified asphalt concrete pavement design contained in Appendix F. (17)

During the paving operation on both projects, a problem was encountered with a few loads of the mix arriving excessively hot at the paving site. When this mix was placed, asphalt visibly bleed up to the pavement surface (Photo #13). At the plant, the rubber-modified asphalt pavement was produced by combining the 400°F aggregates with the 325°F binder mix. Until a temperature equilibrium occurred, the mix appeared to "gain" heat. Consequently, the temperature of the mix at the paving site was hard to directly control from the asphalt plant. The temperature problem encountered at the paving sites was quickly resolved by the asphalt plant making small temperature adjustments. (17)

Photo #13 - The asphalt bled to the pavement surface when the temperature of the rubber-modified asphalt mix was excessively hot.
Morse Brothers Construction produced the rubber-modified asphalt concrete pavement for both projects. Their batch plant normally produced 165 tons/hour of a conventional asphalt mix but with the rubber-modified mix, were only producing 105 tons/hour. They had been producing this product for at least 4 years and this was the first year mix gradation problems were not encountered. The previously experienced gradation problems were attributed to the use of non-standard sieves. (17)

The County Engineer on these two paving projects was very pleased with the performance of the rubber-modified asphalt concrete pavement during and after its placement. During placement, the rubber-modified mix appeared to "flow" due to a 1 to 2 percent higher asphalt content than a conventional asphalt mix. No shoving or deformation of the mat occurred during the roller operation. Specified compactions were achieved without any problems. The mix did retain heat longer so the total paving operation required more time. Nuclear density measurements could not be made until the mat had cooled down enough to prevent the rebounding of the crumb rubber particles, approximately 3 hours. (17)

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<tr>
<td>1990</td>
<td>Evergreen Rd.</td>
<td>Benton County</td>
</tr>
<tr>
<td>1990</td>
<td>Alpine Cutoff</td>
<td>Benton County</td>
</tr>
</tbody>
</table>

Information supplied by Agency and/or Manufacturer (PAVETECH Corp., Seattle, Washington)

Washington

In August of 1983, FHWA Western Federal Lands Highway Division placed a 1.11 mile test section of rubber-modified asphalt pavement on U.S. Forest Service Road 2500 near Mount St. Helen in the Gifford Pinchot National Forest. The overlay was designed for the predicted heavy truck traffic from planned sales of blown down timber from the May 18, 1980 eruption of Mount St. Helens. The overlay was placed in two layers and varied in thickness from 1.75" to 3.5". To evaluate the performance of this CRA process, a half-mile control test
section of 1.75" thick conventional asphalt pavement was placed abutting the 1.75" thick section of rubber-modified asphalt pavement. (7)

Both laboratory and field testing was performed on the test sections to evaluate the performance of the rubber-modified asphalt pavement. Laboratory tests were performed on cores taken from both test sections shortly after construction and each following year for three years. The laboratory tests performed were specific gravity, diametral resilient modulus, diametral fatigue, Hveem stability, and indirect tension. Field tests for deflection, roughness, and skid resistance were performed shortly after construction and then again three years later. In 1985, field surface texture tests were also performed. (7)

The results of the laboratory tests indicated that even though the rubber-modified asphalt pavement hardened slightly faster, it could be expected to have a longer fatigue life than the conventional asphalt pavement. It also had lower skid numbers (dry surface), slightly more macro-texture, and a slightly rougher riding surface. The conventional asphalt pavement did have greater strength results from the indirect tension test. Visual surveys indicated that both the rubber-modified asphalt pavement and the conventional pavement test sections were performing good with no rutting or other pavement distresses apparent. Low Hveem stability results on the rubber-modified asphalt pavement did not correspond with the visual survey results. It was determined that this test could not accurately measure the stability of rubber-modified asphalt pavement. (7)

Currently, the rubber-modified asphalt pavement has been performing good with no pavement distresses visibly apparent. The traffic volume on this road has been lower than predicted since the heavy logging truck traffic did not occur. This is felt to have contributed to the good performance of the rubber-modified asphalt pavement. (7)

**TABLE 6 - RUBBER-MODIFIED ASPHALT PROJECTS IN WASHINGTON**

<table>
<thead>
<tr>
<th>DATE</th>
<th>LOCATION</th>
<th>AGENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>U.S. Forest Rd. 2500, Mount St. Helens area, Gifford Pinchot National Forest</td>
<td>FHWA-WFLHD</td>
</tr>
</tbody>
</table>

Information supplied by Agency and/or Manufacturer (PAVETECH Corp., Seattle, Washington)
"Generic" Rubber-Modified Asphalt Process

- Alaska, Idaho, and Washington

No "generic" rubber-modified asphalt concrete pavement has been used in Alaska, Idaho, and Washington.

- Oregon

In the Spring 1990 issue of the "Oregon Roads Newsletter", DEQ/METRO announced that they were looking for paving projects for their Rubber-Modified Asphalt Concrete Paving Demonstration Project. They were specifically looking for two projects to use the "generic" rubber-modified asphalt concrete pavement specification that was being developed by TAK Associates for use in Oregon. As part of the demonstration projects, meetings and workshops were held to assist prospective agencies on the demonstration project and the "generic" specification. (18)

Four agencies submitted prospective paving projects for DEQ/METRO's demonstration project. Three of the projects proposed to use the "generic" specification: the City of Hillsboro, the City of Portland, and Multnomah County. By the end of the summer, the City of Hillsboro postponed their project until the spring of 1991. The remaining two "generic" projects were scheduled for mid-September but were finally cancelled when the specified crumb rubber gradation (minus #40 sieve) was unattainable from the supplier. Multnomah County postponed their paving project until spring 1991. They still are proposing to use the "generic" rubber-modified asphalt concrete pavement. The City of Portland performed their paving project but used conventional asphalt concrete pavement. (18)

Currently, the draft "generic" specification for rubber-modified asphalt concrete pavement in Oregon is being refined. FHWA, ODOT, asphalt producers, and others are assisting in the development of the "generic" specification by reviewing and suggesting changes wherever applicable. Implementation of the DEQ/METRO Rubber-Modified Asphalt Concrete Paving Demonstration project is expected to resume in the Spring of 1991. (18)

CONCLUSIONS

The States in Region 10 have experienced variable performance with CRA asphalt concrete pavement. Consistently, they have reported problems with the CRA product quality control during production. The gap-graded design of the "dry" CRA process has been hard to achieve. The crumb rubber and asphalt contents have been hard to achieve for both the "dry" and the "wet" processes. During placement, adequate compaction was a problem commonly encountered with both processes that almost always resulted in the pavement raveling. With time and the producer's experience using these CRA processes, the product quality control should improve.
The States in Region 10 have reported improvements in pavement characteristics with the use of the CRA processes. The "wet" process has been reported to have improved resistance to reflective cracking. Alaska, Oregon, and Washington have also reported improved resistance to cracking with the "dry" process. Alaska has attributed the improved stopping distances on icy roads to the "dry" process. (1)

More research is still needed for the CRA processes to be considered technically sound paving products. Currently, it has not been determined if the CRA pavements are recyclable. Also, the effect that the emissions from the production of these CRA processes have on the air quality has not been determined. These two environmental questions should be answered before the CRA processes are considered technically viable. (1)

For the CRA processes to be considered viable solutions to our nations waste tire problem, these processes also need to be economically feasible to use. The "wet" and "dry" processes are both expensive compared to conventional asphalt due to their proprietary nature. It is anticipated that with the development of a "generic" process that the cost of the CRA processes will decrease (1). The cost of the CRA processes is also affected by the limited number of crumb rubber producers (Table 7). Again, it is anticipated with an increased use of crumb rubber, that the producers will increase and the cost of the crumb rubber will decrease (1).

Our nations waste tire stockpiles are indeed a problem. The CRA processes are very promising as one way to help solve the problem. Using scrap tires as a lightweight fill is also another very promising use of waste tires. More research is needed before the CRA processes can responsibly be used to help solve our nations waste tire stockpile problem.

**TABLE 7 - CRUMB RUBBER PRODUCERS**

<table>
<thead>
<tr>
<th>Producer</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlos Rubber Inc.</td>
<td>Los Angeles, CA</td>
</tr>
<tr>
<td>Baker Rubber Inc.</td>
<td>South Ben, IN</td>
</tr>
<tr>
<td>International Rubber Inc.</td>
<td>Chandler, AZ</td>
</tr>
<tr>
<td>Rouse Rubber Industries Inc.</td>
<td>Vicksburg, MS</td>
</tr>
<tr>
<td>Rubber Granulators Inc.</td>
<td>Everett, WA</td>
</tr>
<tr>
<td>Sparton Enterprises</td>
<td>Barberville, OH</td>
</tr>
<tr>
<td>Tire Recyle</td>
<td>Kenner, LA</td>
</tr>
<tr>
<td>W.R.C. Inc.</td>
<td>Castle Rock, CO</td>
</tr>
</tbody>
</table>
Mr. Chairman and Members of the Committee; thank you for providing the Federal Highway Administration (FHWA) the opportunity to testify before your Committees on an area in which we have been involved for some years.

The issue of scrap tires and their potential use as an additive for asphalt paving products has technical, economic, and environmental implications. Even though the technology exists to incorporate scrap tire rubber into asphalt paving products, there are still some long term effects from using this recycled product which have not been adequately addressed. My testimony provides an overview of the Federal Highway Administration’s background on these matters, a summary of the state-of-the-practice, a discussion of our long term concerns, a picture of the present and projected costs, and our proposed future program in this area.
BACKGROUND

FHWA has been involved with the use of crumb rubber since the early 1970's. In 1976, an FHWA Demonstration Project (Demo Project No. 37 "The Use of Discarded Tires in Highway Construction") resulted in the construction of 40 projects using asphalt-rubber binder in a pavement surface treatment. In 1983, FHWA initiated Experimental Project No. 3 "Asphalt Additives." Projects using asphalt-rubber and rubber modified hot mix asphalt mixtures are being evaluated. We have co-sponsored three National Seminars on Asphalt-Rubber which provided industry, academia, and user agencies a forum to share this technology. Most recently, we have assigned a full time engineer in the Pavement Design and Rehabilitation Branch to examine and monitor the performance of asphalt mixes with crumb rubber.

STATE OF THE PRACTICE

"Crumb rubber additive" (CRA) is our generic term for the product from scrap tires which can be used in the asphalt products. It is the product from the ambient grinding of waste tires and from retread buffing waste. Tires can be ground by a cryogenic method, but the product is less suitable as CRA. The size (gradation) of the CRA is dependent on the process and application it will be used for. Typically, a fine ground CRA passes a No.20 Sieve (0.04 inches) and is retained on a No.50 Sieve (0.01 inches), similar to fine beach sand. A coarse ground CRA passes a No.4 Sieve (0.19 inches) and is retained on a No.20 Sieve (0.04 inches), like a coarse sand.
Adding CRA to asphalt paving products can be divided into two basic processes commonly described as the 'wet process' and the 'dry process.' The wet process blends CRA with hot asphalt cement and allows the rubber and asphalt to fully react in mixing tanks to produce an asphalt-rubber binder. This binder can contain as much as 30% CRA. Both the wet process and the products which use asphalt-rubber binder are protected by patents.

The dry process mixes CRA with the hot aggregate at the hot mix asphalt facility prior to adding the asphalt cement. Depending on the type of facility and the hot mix process, some degree of rubber/asphalt reaction takes place. This dry process produces a rubber modified hot mix asphalt mixture. These mixes can contain as much as 3% CRA by total weight of mix. "Plusride" is a patented product of the dry process, but the process itself, to the best of our knowledge, is in the public domain.

Laboratory test results show that adding CRA to asphalt paving products can improve the engineering characteristics of the asphalt binder. However, extrapolation of laboratory test results to field performance has not always provided reasonable correlations. The principle deterrent to using CRA has been cost. State and local agencies are reluctant to use paving materials which have a significantly higher cost and do not have equally higher performance records.
There are four general categories of asphalt paving products which use CRA. They are crack/joint sealants, surface treatments, hot mix asphalt mixtures with asphalt-rubber binder, and rubber modified hot mix asphalt mixtures. Crack/joint sealant is an asphalt-rubber product, blending 15 to 30% CRA with the asphalt cement. This product is routinely used in many States as a maintenance material and is covered in the American Society for Testing and Materials specifications (ASTM D3406).

Surface treatments also use an asphalt-rubber binder with a similar amount of CRA. The binder is applied to the roadway surface at 0.6 gallons per square yard, then covered with aggregate and seated with a roller. This application of CRA began in the late 1960's and was patented under the trade names SAM and SAMI (Stress Absorbing Membrane and Stress Absorbing Membrane Interlayer). Under FHWA Demonstration Project No. 37, 40 SAM and SAMI projects were constructed and evaluated. This technology has been proven and documented, but the cost is higher than conventional asphalt surface treatments.

By the late 1970's the producers of asphalt-rubber binder began experimenting with the use of asphalt-rubber binder in hot mix asphalt mixtures. Again, the amount of CRA added to the asphalt cement is generally 15 to 30%. The research has shown that the amount of binder required in the mixes will increase over conventional asphalt mixes. Unfortunately, there have not been
many controlled experimental projects of this material to evaluate its performance in comparison to conventional hot mix asphalt mixes.

The remaining category of asphalt paving products are the rubber modified hot mix asphalt mixtures. These products use the dry process to add 1 to 3% CRA to the total mix. This technology was developed in Sweden and introduced in the United States in the 1970's as the patented product, Plusride. FHWA Experimental Project No. 3 is evaluating projects constructed with this product. To date, the evaluations have observed both successes and failures. Examination of the dry process, outside of the patented Plusride technology, have just begun in several states. A number of years will be required to evaluate the performance of these new mixes before any performance history can be determined.

RESEARCH
Although the technology exists today to incorporate the rubber from scrap tires into asphalt paving products, a number of long term issues must be addressed before these products, particularly the hot mix asphalt products, can be considered technological and environmental advances. If the highway agencies were directed to use CRA today, and the products using CRA failed to satisfy these long term issues, we could be creating a problem many times greater than the problems we are trying to resolve.
From the FHWA perspective, we must evaluate the field performance of the various mixes to determine if they are cost effective to the highway community. Acceptance and use of these products by the State highway agencies will depend greatly on the life cycle cost effectiveness. Any increase in product cost must be offset by an equal or greater increase in pavement performance. There is very limited comparable data on the performance of hot mix asphalt mixtures using CRA. If the performance does not outweigh the additional cost, there is no economical benefit to the highway community.

The recycling of hot mix asphalt mixes has become a significant portion of the paving program in many states. The ability to recycle mixes which have CRA has never been evaluated and documented. If pavements with this additive cannot be recycled, we will have to deal with the disposal of these pavements. Even if we can successfully recycle the mix, we must also consider what effects the recycling process will have on the properties of the mix. This issue will require a combined effort of the highway community.

Our other long term concern with using CRA relates to the environment. Only a limited amount of testing has been performed to measure the emissions associated with processing asphalt paving products with CRA. The emissions from producing, placing, and recycling these mixes are regulated by federal, state, and local emission standards. We intend to comply with these standards on
federal-aid projects and feel that some additional testing, evaluation, and documentation is needed.

MATERIAL COST
There is an increased cost associated with using CRA over conventional asphalt products. Under present day budget constraints, if the paving product cost is 30% higher, then 30% less roadway can be paved. Surface treatments with asphalt-rubber binder have only been shown to be cost comparable to other pavement rehabilitation techniques in certain situations. There is only limited performance history on the use of CRA in hot mix asphalt mixtures. After the long term performance data is collected, the life cycle cost of these mixes can be better established. The use of CRA in asphalt pavements may prove to be cost effective once patent barriers are addressed and the long term performance evaluations are completed. In general, paving products with CRA presently cost 50 to 100% more than conventional asphalt products.

CONCLUSIONS
The use of crumb rubber additive (CRA) in asphalt paving products has the potential to enhance the pavement and to reduce an environmental problem. However, we must address several long term issues before the products will be acceptable to the user agencies. The present cost to use CRA is only representative of a
limited market. FHWA's preliminary projections indicate that the full production cost for asphalt-rubber and rubber modified mixes will be 20 to 30% higher than conventional asphalt mixes.

The paving industry presently consumes the rubber from one to two million scrap tires each year in the form of CRA. If these products can demonstrate cost effective performance and are environmentally acceptable, then CRA could become a significant alternative use for waste tires.

FHWA PROGRAM

FHWA continues to encourage the State highway agencies to evaluate asphalt additives, including CRA. Our engineering staff is available to assist State and local agencies in the development of asphalt paving products with CRA. We plan to continue to monitor the performance of CRA projects to establish its cost effectiveness and we will examine the recycling issue. We are presently developing our "Research And Technology Program 1992-1996". In the "Research and Development: Pavements and Structures Element" of this program, the "Materials to Strengthen and Enhance Performance Objective" includes enhancing the application of waste materials for use in highway construction.

Thank you for the opportunity to express the Federal Highway Administration's position on the use of crumb rubber additive for asphalt paving. I would be pleased to address any questions you may have.
(a) **Steel-wheeled rollers** - Steel-wheeled roller shall have:

- Rollers shall have fully operational water spray bars to coat the roller drum with water mixed with a wetting agent.
- Use of a wetting agent such as tri-sodium phosphate is recommended.
- A gross static weight of at least 8 tons.
- A static weight on the drive wheel of at least 250 pounds per inch of width.

If used for finish rolling:

- A gross static weight of at least 6 tons.
- No drive wheel static weight requirement.

(b) **Vibratory rollers** - Vibratory rollers shall:

- Be equipped with fully operational water spray bars to coat the roller drum with water mixed with a wetting agent.
- Use of a wetting agent such as tri-sodium phosphate is recommended.
- Be equipped with amplitude and frequency controls.
- Be specifically designed to compact AC.
- Be capable of at least 2,000 vibrations per minute.

If used for finish rolling:

- Have a gross static weight of at least 6 tons.
- Not be operated in the vibratory mode.

(c) **Pneumatic-tired rollers** - Pneumatic-tired rollers shall:

- Not be used.

403.34 Drying and Heating Aggregate and AC

Add the following to this subsection:

(e) Heating Temperatures for Rubber Modified Asphalt Concrete—
Heat the asphalt to at least 250 F but not more than 350 F, when it enters the mixer. The maximum temperature of RUMAC at
discharge from the mixer and minimum temperature when placed shall be as follows:

<table>
<thead>
<tr>
<th>Grading</th>
<th>Max. at mixer</th>
<th>Min. Behind Paver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense</td>
<td>350 F</td>
<td>285 F</td>
</tr>
<tr>
<td>Open</td>
<td>350 F</td>
<td>250 F</td>
</tr>
</tbody>
</table>

**403.39 Compaction**

Add the following to this subsection:

(f) Compaction - Rollers and compacting procedure shall conform to the requirement of Section 403.24, Compaction, supplemented with the following:

The proper rolling procedure shall be established with a control strip to determine the equipment and number of roller passes necessary to obtain a target density with a minimum of 94% of maximum theoretical density. The contractor shall use a nuclear density gauge to measure the required density. Pneumatic-tired rollers shall not be used. Traffic shall not be allowed on the new surface until the temperature of the mat has dropped below 140°F.

**403.35 Mixing**

Add the following to this subsection:

(a) Mixing Rubber Modified Asphalt Concrete - The contractor shall submit to the engineer not less than fourteen (14) calendar days before production of RUMAC a work plan describing his planned procedures for mixing. The plan shall include such details as the method of introducing granulated whole used tire rubber into the mixture, mixing times, temperatures and equipment. No mixing of the material will be allowed until the engineer has approved the work in writing. For batch plants, the aggregates and granulated rubber shall be combined and mixed thoroughly for a minimum of 25 seconds, prior to introducing the bituminous materials.

**Basis of Payment**

The unit price bid per ton for rubber modified bituminous plant mix shall include the cost of furnishing all materials including granulated rubber and all equipment and labor necessary to complete the work.
APPENDIX B
Note: Attached are "Notes to Engineer" which are referenced by an superscript letter (i.e. Z). It is important that these notes be referred to when developing a specification from this guide for highway, road, street, and airport asphalt-rubber paving projects.

1. Scope

This specification covers material, equipment, and construction procedures for asphalt concrete pavement using a reacted asphalt-rubber binder.

2. Prequalification of A New Asphalt-Rubber Material

Prequalification of a new asphalt-rubber material or applicator/supplier may be requested at any time. Prequalification will be based on three controlled field applications evaluated after three years’ performance under traffic. The controlled field applications may be of other construction related uses utilizing asphalt-rubber materials. New asphalt-rubber material that has been evaluated and prequalified by an agency recognized nationally may be prequalified by that agency upon disclosure of suitable evidence of successful performance. Notwithstanding other agency prequalification, this agency reserves the right to withhold prequalification pending the performance evaluation of local controlled field applications.

3. Asphalt-Rubber Binder

3.1 General: The asphalt-rubber binder shall be a uniform reacted blend of compatible paving grade asphalt cement, granulated reclaimed vulcanized rubber, extender oil, if required, and liquid anti-stripping agent when indicated by standard moisture susceptibility tests. The asphalt-rubber binder shall be Type I, Type II, or Type III binder and shall meet the physical parameters listed in Table 1 for the type of binder specified when reacted at 350 degrees F +/- 10 degrees F for 60 minutes.

Revised September 19, 1990
TABLE 1

SPECIFICATIONS FOR ASPHALT-RUBBER BINDER

<table>
<thead>
<tr>
<th>Specification</th>
<th>Type I (a)</th>
<th>Type II (b)</th>
<th>Type III (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Viscosity, 347°F Spindle 3, 12 RPM, cps (ASTM 2669)</td>
<td>Min 1,000</td>
<td>Max 4,000</td>
<td>Min 1,000 Max 4,000</td>
</tr>
<tr>
<td>Penetration, 77°F, 100g, 5 sec.: 1/10 mm. (ASTM D5)</td>
<td>Min 25</td>
<td>Max 75</td>
<td>50 Max 100</td>
</tr>
<tr>
<td>Penetration, 39.2°F, 200g, 60 sec.: 1/10 mm. (ASTM D5)</td>
<td>Min 15</td>
<td>Max 15</td>
<td>25 Max 40</td>
</tr>
<tr>
<td>Softening Point: °F (ASTM D36)</td>
<td>Min 150</td>
<td>Max 120</td>
<td>110</td>
</tr>
<tr>
<td>Resilience, 77°F: % (ASTM D3407)</td>
<td>Min 20</td>
<td>Max 10</td>
<td>0</td>
</tr>
<tr>
<td>Ductility, 39.2°F, 1 cpm: cm. (ASTM D113)</td>
<td>Min 5</td>
<td>Max 10</td>
<td>15</td>
</tr>
<tr>
<td>TFOT Residue, (ASTM D1754) Penetration Retention, 39.2°F: %</td>
<td>Min 75</td>
<td>Max 75</td>
<td>75</td>
</tr>
<tr>
<td>Ductility Retention, 39.2°F: %</td>
<td>Min 50</td>
<td>Max 50</td>
<td>50</td>
</tr>
</tbody>
</table>

a. Type I Hot Climate - Average July max 110°F Average Jan. low 30°F or above

b. Type II Moderate Climate - Average July max 100°F Average Jan. low 15-30°F

c. Type III Cold Climate - Average July max 80°F Average Jan. low 15°F or lower

Revised September 19, 1990
3.2 MATERIALS

1 Asphalt Cement: The asphalt cement for the asphalt-rubber binder shall comply with requirements of ASTM D 3381 and AASHTO M-226. The grade selected shall be determined by laboratory testing performed by the asphalt-rubber supplier to insure appropriate compatibility and reacting characteristics.

2 Asphalt Extender Oil: An asphalt-extender oil may be added, if necessary, to meet the requirements of Table 1. Extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements:

- Viscosity, SSU, at 100 degrees F (ASTM D88) 2500 min.
- Flash Point, COC, degrees F (ASTM D92) 390 min.
- Molecular Analysis (ASTM D 2007):
  - Asphaltenes, Wt. % 0.1 max.
  - Aromatics, Wt. % 55.0 min.

3 Granulated Reclaimed Vulcanized Rubber

1 General: The ground tire rubber shall be produced from processing automobile and/or truck tires by ambient grinding methods. The rubber shall be substantially free from contaminants including fabric, metal, mineral, and other non-rubber substances. The rubber shall be sufficiently dry to be free flowing and not produce a foaming problem when added to hot asphalt cement. Up to 4% by weight of talc or other appropriate blocking agent can be added to reduce agglomeration of the rubber particles.

2 Physical Requirements

1 Gradation and Particle Length: When tested in accordance with ASTM C-136 using a 50 gram sample, the resulting rubber gradation shall meet the following gradation limits for the type of rubber specified.
Percent Passing

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Type II Open or Gap Graded</th>
<th>Type III Dense or Gap Graded</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 8</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>No. 10</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No. 16</td>
<td>75 - 100</td>
<td>98 - 100</td>
</tr>
<tr>
<td>No. 30</td>
<td>25 - 60</td>
<td>70 - 100</td>
</tr>
<tr>
<td>No. 50</td>
<td>0 - 20</td>
<td>10 - 40</td>
</tr>
<tr>
<td>No. 200</td>
<td>0 - 5</td>
<td>0 - 5</td>
</tr>
</tbody>
</table>

Max. Particle Length 3/16" ---

.2 Fiber Content: The ground rubber shall be designated Grade A or Grade B. For grade A rubber, the fiber content shall be less than 0.1% by weight. For grade B rubber, the fiber content shall be less than 0.5% by weight. Fiber content shall be determined by weighing fiber agglomerations which are formed during the gradation test procedure. Rubber particles shall be removed from the fiber agglomerations before weighing.

.3 Moisture Content: For each rubber type and grade, the moisture content shall be less than 0.75% by weight.

.4 Mineral Contaminants: For each rubber type and grade, the mineral contaminant amount shall not be greater than 0.25% by weight as determined after water separating a 50 gm. rubber sample in a 1 liter glass beaker filled with water.

.5 Metal Contaminants: The rubber shall contain no visible metal particles as indicated by thorough stirring of a 50 gm. sample with a magnet.

.3 Packaging: The ground rubber shall be supplied in moisture resistant disposable bags which weigh either 50 +/- 2 Lbs. or 60 +/- 2 Lbs. The bags shall be palletized into units each containing 50 bags to provide net pallet weights of either 2500 +/- 100 lbs. or 3000 +/- 100 lbs. Glue shall be placed between layers of bags to increase the unit stability during shipment. Palletized units shall be double wrapped with U. V. resistant stretch wrap.

.4 Labeling: Each bag of rubber shall be labeled with the manufacturer

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designation for the rubber, the specific type, and grade of rubber in accordance with this specification (example - Type I, Grade A), the nominal bag weight designation (50 or 60 lb.), and manufacturer lot number designation. Palletized units shall contain a label which indicates the manufacturer designation, rubber grade and type, net pallet weight, and production lot number.

5 Certification: The manufacturer shall ship along with the rubber, certificates of compliance which certify that all requirements of this specification are complied with for each production lot number or shipment.

4 Anti-Stripping Agent: If required by the Job-Mix Formula to produce appropriate water resistance, an anti-stripping agent that is heat stable and approved for use by the specifying agency shall be incorporated into the asphalt-rubber material at the percentage required by the job mix formula. It shall be added to the asphalt cement prior to blending with the granulated rubber.

3.3 ASPHALT-RUBBER BINDER MIXTURE DESIGN: The mixture design shall be performed by the asphalt-rubber supplier. The proportion of granulated rubber shall be between 15 and 20 percent by weight of the total mixture.

The asphalt-rubber supplier shall supply to the engineer a blend formulation at least 10 days before pavement construction is scheduled to begin. The blend formulation shall consist of the following information:

Asphalt Cement
Source of Asphalt Cement
Grade of Asphalt Cement
Source and Grade of Extender Oil
Percentage of Asphalt Cement and Extender Oil by Total Weight of the Asphalt-Rubber Blend

Granulated Reclaimed Rubber
Source of Granulated Rubber
Grade of Granulated Rubber
Percentage of Granulated Rubber by Total Weight of the Asphalt-Rubber Mixture

If granulated rubber from more than one source is utilized the above information will be required for each granulated rubber used.

Anti-Strip Agent
Source of Anti-Strip
Percentage of Anti-Strip by Weight of the Asphalt

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Physical properties of the blend in accordance with Table 1.

3.4 ASPHALT-RUBBER MIXING AND PRODUCTION EQUIPMENT: All equipment utilized in production and proportioning of the asphalt-rubber binder shall be described as follows:

1. Asphalt Heating Tank: An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the granulated rubber. This unit shall be capable of heating a minimum of 3,000 gallons of asphalt cement.

2. Blender: The asphalt-rubber mechanical blender with a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and granulated rubber, at the mix design specified ratios, as directed by the engineer. This unit shall be equipped with a granulated rubber feed system capable of supplying the asphalt cement feed system, as not to interrupt the continuity of the blending process. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons per minute.

3. Storage Tank: An asphalt-rubber storage tank equipped with a heating system to maintain the proper temperature for pumping and adding of the binder to the aggregate and an internal mixing unit within the storage vessel capable of maintaining a proper mixture of asphalt cement and granulated rubber.

4. Supply System: An asphalt-rubber supply system equipped with a pump and metering device capable of adding the binder by volume to the aggregate at the percentage required by the job-mix formula.

5. Temperature Gage: An armored thermometer of adequate range in temperature reading shall be fixed in the asphalt-rubber feed line at a suitable location near the mixing unit.

3.5 ASPHALT-RUBBER MIXING AND REACTION PROCEDURE

1. Asphalt Cement Temperature: The temperature of the asphalt cement shall be between 375 and 425 degrees F at the addition of the granulated rubber.

2. Blending and Reacting: The asphalt and granulated rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the granulated rubber is added to the asphalt cement. Temperature of the asphalt-rubber mixture shall be maintained between 325 degrees F and 375 degrees F during the reaction period.

Revised September 19, 1990
.3 Transfer: After the material has reacted for at least 45 minutes, the asphalt-rubber shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the job-mix formula.

.4 Delays: When a delay occurs in binder use after its full reaction, the asphalt-rubber shall be allowed to cool. The asphalt-rubber shall be reheated slowly just prior to use to a temperature between 325 degrees and 375 degrees F, and shall also be thoroughly mixed before pumping and metering into the hot plant for combination with the aggregate. The viscosity of the asphalt-rubber shall be checked by the asphalt-rubber supplier. If the viscosity is out of the range specified in Section 3 of this specification, the asphalt-rubber shall be adjusted by the addition of the either asphalt cement or granulated rubber as required to produce a material with the appropriate viscosity.

4. ASPHALT-RUBBER CONCRETE

4.1 MINERAL AGGREGATE

.1 General: The aggregate for the asphalt concrete mixture shall be composed of hard durable particles of crushed stone, crushed gravel, crushed slag, or expanded clay lightweight aggregate. The aggregate shall be free from organic or decomposed materials, clay balls or lumps, adhered dust and deleterious coatings. Angular natural sand or manufactured sand may be used as the fine aggregate portion. Rounded natural sands are not permitted. Mineral filler, if used, shall meet requirements of ASTM D242 or AASHTO M17.

.2 Physical Requirements

.1 Fractured Faces: The aggregate retained on the No. 4 screen shall consist of at least particles which have at least one fractured or crushed face.

.2 Abrasion Loss: The aggregate shall have an abrasion loss which does not exceed when tested for 500 revolutions in accordance with ASTM C131 or AASHTO T96.

.3 Sand Equivalent Value: The sand equivalent value of the aggregate shall be a minimum of when tested in accordance with ASTM D2419 or AASHTO T176.

.4 Gradation: The gradation of the aggregate shall meet the following limits when tested in accordance with ASTM C136 or AASHTO T27.
Guide Specification for Open, Dense and Gap Graded Asphalt Concrete with Asphalt-Rubber Binder

Sieve Size % Passing

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td></td>
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<td>3/8&quot;</td>
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<td>No. 30</td>
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<td>No. 50</td>
<td></td>
</tr>
<tr>
<td>No. 200</td>
<td></td>
</tr>
</tbody>
</table>

4.3 BLOTTER REQUIREMENTS: Blotter material, if required, shall be composed of fine aggregate or sand meeting the following gradations requirements when tested in accordance with ASTM C136 or AASHTO T27.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>75-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>45-80</td>
</tr>
<tr>
<td>No. 50</td>
<td>10-30</td>
</tr>
<tr>
<td>No. 100</td>
<td>0-10</td>
</tr>
</tbody>
</table>

5. JOB-MIX FORMULA

5.1 MIXTURE DESIGN: The mixture design shall be performed by the asphalt-rubber supplier, the agency, or an approved laboratory, and shall be used as the basis for determining the job-mix formula. The design method used shall be in accordance with __________. The mixture design shall be submitted to the engineer at least 10 days prior to construction. Based on information contained in the mixture design, the engineer shall approve a job-mix formula with the following tolerances allowed for single tests on aggregate gradation and asphalt-rubber binder content.

JOBS MIX TOLERANCE

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot; and larger</td>
<td>+/- 8</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>+/- 7</td>
</tr>
<tr>
<td>No. 4, No. 8</td>
<td>+/- 6</td>
</tr>
<tr>
<td>No. 30, No. 50</td>
<td>+/- 5</td>
</tr>
<tr>
<td>No. 200</td>
<td>+/- 3</td>
</tr>
</tbody>
</table>

Revised September 19, 1990
The mixture design shall include sufficient test results and documentation to assure that all requirements for the aggregate (Section 4) and the asphalt-rubber binder (Section 3) are fulfilled.

5.2 JOB-MIX FORMULA: The mixture design shall recommend the job-mix formula and shall list the following information:

1. Aggregate
   - source and identification (for each material used)
   - gradation (for each material used)
   - blend percentage
   - mixture gradation

2. Asphalt-Rubber
   - source and grade of asphalt cement
   - source and type of extender oil
   - source and identification of granulated rubber
   - granulated rubber percentage for the asphalt-rubber binder
   - type and amount of additive(s), if required
   - temperature when added to aggregate

3. Recommended asphalt-rubber binder content by both weight of total mix and weight of dry aggregate.

4. Recommended mixture production temperature.

5. Recommended lay down temperature.

6. Recommended production temperature.

6. CONSTRUCTION EQUIPMENT

6.1 ASPHALT-RUBBER/AGGREGATE MIXING EQUIPMENT: The addition and mixing of the asphalt-rubber with the aggregate shall be accomplished with one of the following types of hot-mix asphalt plants.

Batch Mixing - Batch mix plant consisting of cold aggregate storage and feed, drier, gradation control unit, hot aggregate storage bins, aggregate weigh-hopper, and a twin-shaft pugmill mixing unit. Also, the plant may be equipped with hot-mix surge or storage bins for short-term holding of the mixture until spreading.

Revised September 19, 1990
Drier-Drum Mixing - Drier-drum mix plant consisting of cold aggregate storage and feed, automatic weighing system, drier-drum mixer and hot-mix surge or storage bins for short term holding of the mixture until spreading.

The asphalt-rubber/aggregate mixing equipment shall be capable of producing a paving mixture meeting all of the requirements contained in this specification. Specifically the plant shall provide proper aggregate gradation, asphalt-rubber binder content and mixing temperature.

6.2 MIXTURE SPREADING EQUIPMENT: Paving shall be accomplished with self-propelled, mechanical spreading and finishing equipment, pneumatic tire or tracked type, having a tamping bar or vibratory screed or strike-off assembly capable of distributing the material to not less than the full width of a traffic lane and to the depth needed to achieve the minimum compacted thickness or finished grade as required. The screed or strike-off assembly shall be equipped with a heating unit that maintains the temperature needed to prevent tearing of the paving mixture during spreading. Pavers that leave ridges, indentations or other marks in the surface that cannot be eliminated by rolling or prevented by adjustment in operation of the equipment shall not be used.

6.3 HAULING EQUIPMENT: Trucks for hauling the paving mixture shall be tailgate discharge, dump or moving bottom (horizontal discharge) type, and compatible with the spreading equipment. If a dump unit is utilized, the bed will not push down on the paver receiving hopper when fully raised or have too short a bed which results in mixture spillage in front of the paver.

The trucks shall be equipped, when ordered by the engineer, with a canvas or similar covering so as to prevent rapid mixture heat loss during cooler weather or as a result of long hauling distances.

6.4 COMPACTION EQUIPMENT: Rollers shall be self-propelled, 2-axle(tandem) steel-wheel type and shall have a minimum weight of 8 tons. For open-graded surface mixtures, maximum roller weight shall be 10 tons and for dense and gap-graded mixtures, maximum roller weight shall be 12 tons. All rollers shall be equipped with pads and a watering system to prevent sticking of the paving mixture to the steel-tired wheel (drums). Vibratory rollers should be used for breakdown passes on dense and gap-graded mixes only. Unless otherwise permitted by the engineer, the contractor shall furnish a minimum of two of the rollers as described above. Pneumatic-tired rollers will not be used, due to the increased adhesiveness of the asphalt-rubber binder.

6.5 Blotter Spreading Equipment: Blotter shall be spread using hopper or whirl type tailgate spreaders.

7. CONSTRUCTION PROCEDURES

Revised September 19, 1990
7.1 GENERAL: Potholes and other areas of pavement failure and major depressions in the existing pavement surface shall be repaired by patching with asphalt concrete.

Cracks greater in width than 1/4 inch shall be repaired by cleaning, routing and filling with an appropriate sealant.

Immediately prior to application of a tack coat, the surface shall be thoroughly cleaned by sweeping.

7.2 TACK COAT:

7.3 ASPHALT-RUBBER PRODUCTION RECORDS: The asphalt-rubber supplier shall maintain records indicating for each batch of asphalt-rubber binder produced the quantity of asphalt cement in gallons, the temperature of the asphalt cement, the amount of anti-stripping or other additives, if used, in gallons, and the quantity of granulated rubber in pounds. This information shall be provided to the engineer on a daily basis.

7.4 ASPHALT-RUBBER/AGGREGATE MIXTURE PREPARATION: The asphalt-rubber binder shall be at a temperature of 325 degrees F to 375 degrees F when pumped and metered into the mixing plant.

The aggregate shall be dried and heated to provide a paving mixture immediately after mixing, having a temperature of _____ and a moisture content not exceeding 1.0 percent by weight of mixture.

The mixing operation shall be sufficient to achieve a satisfactory mixture with a minimum of 95% coated particles as determined by AASHTO T195 or ASTM D2489.

If the mixture is discharged from the mixer into a hot-mix surge or storage bin, the bin shall be operated so that segregation of the mixture will be minimized.

7.5 HAULING OF ASPHALT-RUBBER/AGGREGATE MIXTURE: Truck beds shall be clean of materials such as dirt, mud and aggregates. Just prior to loading of the mixture, the truck bed shall be sprayed with a light application of a soapy solution or a silicone emulsion (oiling with kerosene or diesel fuel will not be permitted due to adverse effects on the binder) to reduce sticking of the mixture to the truck bed.

When directed by the engineer, the mixture shall be covered with a canvas or similar covering to prevent rapid cooling.

7.6 SPREADING OF ASPHALT-RUBBER/AGGREGATE MIXTURE: The mixture shall be placed and finished by means of paving equipment as required by Section 6.2
except under certain conditions or at certain locations where the engineer determines use of self-propelled pavers impractical. The temperature of the mixture immediately behind the paver shall be between ____ and ____° degrees F.

The paving equipment shall place the mixture without segregation or tearing within the specified tolerances and true to the line, grade and crown indicated on the plans. In order to achieve a continuous spreading operation, the speed of the paver shall be coordinated with the production of the mixing plant.

The width of each pass of the paver shall be limited to the maximum width of the heated screed or strike-off assembly and side augers. The screed may be extended, at the discretion of the engineer, beyond the end of the auger for short distances where irregularities in the pavement width occur.

The mixture shall not be placed on any wet surface or when weather conditions will otherwise prevent it from proper handling or finishing. The mixture shall be placed only when the atmospheric temperature is at least 60 degrees F for open-graded mixes and at least 50 degrees F for dense-grades mixes.

7.7 COMPACTION OF ASPHALT-RUBBER/AGGREGATE MIXTURE: The mixture shall be rolled by means of the compaction equipment as required by Section 6.4. A minimum of two rollers shall be used for mixture compaction unless otherwise directed by the engineer. The steel-tired wheel (drums) shall be wetted with plain water or, if necessary, with soapy water to prevent mixture pick-up during rolling.

Initial or breakdown compaction shall commence immediately after mixture spreading and shall consist of ____L coverages unless otherwise directed by the engineer to prevent damage to the course being compacted. A coverage shall be as many passes as are necessary to cover the entire width being paved, with a pass being one movement of a roller in either direction. Each coverage shall be complete before subsequent coverages are started. Final rolling consisting of not less than one complete coverage, shall be used to smooth the surface of the mat. All rolling shall be accomplished without excessive aggregate fracturing or mixture shoving.

7.8 APPLICATION OF BLOTTER MATERIALS: The application of blotter material (usually 1 to 2 pounds per square yard) meeting the requirements of Section 4.2 may be required on a warm mat before opening to traffic. The use, rate and locations for blotter material shall be designated by the engineer. Any blotter material shall be uniformly applied using equipment specified in Section 6.5.

7.9 TRAFFIC CONTROL: Traffic shall be directed through the project with such signs, barricades, devices, flagmen, and pilot vehicles as may be necessary to provide the maximum safety for the public and the workmen with minimum interruption of the work and to protect the mat from damage until sufficiently cooled or covered with.
blotter to carry traffic.

8. METHOD OF MEASUREMENT AND BASIS OF PAYMENT

8.1 ASPHALT-RUBBER BINDER: The asphalt-rubber shall be measured and paid for per ton of binder in the mixture under Asphalt-Rubber Binder which includes asphalt cement extender oil and granulated rubber.

8.2 ANTI-STRIP: 

8.3 ASPHALT-RUBBER CONCRETE: The asphalt-rubber/aggregate mixture shall be measured and paid for per ton in-place under Asphalt-Rubber Concrete which includes the mineral aggregate as specified, the binder mixture preparation, hauling, spreading and compaction as specified.

8.4 BLOTTER MATERIAL: The blotter material will be measured and paid for per ton in-place under Blotter Material, as specified.

8.5 TACK COAT: The tack coat will be measured and paid for per ton in-place under Asphalt For Tack Coat, as specified.

8.6 PATCHING: Any pavement patching as specified will be measured and paid for per square yard under Pavement Repair (patching).

8.7 CRACK SEALING: Any crack sealing as specified will be measured and paid for per linear foot under Pavement Repair (crack sealing).

8.8 TRAFFIC CONTROL: The traffic control will be a lump sum item and paid for under Traffic Control, as specified.
NOTES TO ENGINEER

A. Specify that either an open-graded, dense-graded or gap-graded asphalt concrete is to be constructed.

B. The asphalt-rubber binder is available in three types. Type I asphalt-rubber is a low stiffness material suited for use in cold climates, Type II is a moderately stiff material used in moderate climates, and Type III is a high stiffness material which is suitable for hot climates. The first blank in Section 3 should specify the type of asphalt-rubber to be used (Type I, II or III).

C. It is not necessary, and is sometimes counterproductive, to select the grade of asphalt cement to be used in preparing the asphalt-rubber binder. The asphalt-rubber supplier should be allowed select the grade of asphalt cement that when blended with the rubber will meet the properties specified in Table 1.

If the Engineer wishes to specify an asphalt cement grade the following table presents the grades that are generally used for Types I, II and III binders. If possible, it is recommended that AC or Penetration grade asphalts should be specified since the original and not the aged residue properties of the asphalt cement controls the low temperature properties of the asphalt-rubber.

<table>
<thead>
<tr>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR-1000 w/ extender as required</td>
<td>AR-1000, AR-2000</td>
<td>AR-2000, AR-4000</td>
</tr>
<tr>
<td>AC 2.5 w/ extender if required</td>
<td>AC 2.5, AC 5</td>
<td>AC 10, AC 20</td>
</tr>
<tr>
<td>200-300 w/ extender if required</td>
<td>120-150, 200-300</td>
<td>60-70, 85-100</td>
</tr>
</tbody>
</table>

D. For dense, open or gap graded mix either Grade A or Grade B is acceptable. For spray applications only Grade A rubber should be used since the fibers may clog the spray nozzles.
E. Proper selection of mineral aggregate is very important for production of an asphalt concrete paving mixture containing an asphalt-rubber binder. In addition to the general descriptive requirements contained in Section 4, gradation, fractured faces, abrasion loss, and sand equivalent parameters are used in this specification for identifying aggregates which are appropriate for specific mixtures and traffic conditions. Limits for these parameters are contained in Table 2 for open-graded gap-graded or dense-graded mixtures.

**TABLE 2**

**SUGGESTED GRADATION SPECIFICATION FOR DENSE, OPEN AND GAP-GRADED ASPHALT-RUBBER CONCRETE**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Dense-Graded</th>
<th>Open-graded</th>
<th>Gap-Graded</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>100</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>1&quot;</td>
<td>100</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>90-100</td>
<td>75-95</td>
<td>90-100</td>
</tr>
<tr>
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<tr>
<td>1/2&quot;</td>
<td>60-80</td>
<td>50-70</td>
<td>65-85</td>
</tr>
<tr>
<td>1&quot;</td>
<td>50-70</td>
<td>40-60</td>
<td>50-65</td>
</tr>
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<td>3/8&quot;</td>
<td>40-60</td>
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<td>45-50</td>
</tr>
<tr>
<td>#4</td>
<td>35-50</td>
<td>30-45</td>
<td>30-45</td>
</tr>
<tr>
<td>#8</td>
<td>25-55</td>
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<tr>
<td>#200</td>
<td>2-8</td>
<td>2-8</td>
<td>2-6</td>
</tr>
</tbody>
</table>

1. Fractured Faces (percent by weight of particles retained on the No. 8 sieve with at least 1 fractured surface) 90% Min.

2. Abrasion Loss (ASTM C131 or AASHTO T96) 40% Max.

3. Sand Equivalent (ASTM D2419 or AASHTO T176) 45 Min.

Revised September 19, 1990
The limits contained in Table 2 are intended to be a guide for selection of appropriate aggregates. These limits may be modified for use in areas where aggregates meeting these requirements cannot be produced at a reasonable cost. The use of a standard gradation from a state highway department, city or county that generally follows these guidelines may be used. If such a standard gradation specification is used for dense-graded mixtures, it is important that the design gradation be selected on the coarse side of the band so that sufficient voids are present to accommodate the increased binder content and greater film thickness generally associated with asphalt-rubber paving mixtures.

If it is desired to use aggregates which greatly differ from stated requirements, please contact ISI to assure that appropriate materials are specified.

F. Select who will perform the mix design. It is our recommendation that the asphalt-rubber supplier perform the mix design since they are familiar with the variations in the test procedures required when using asphalt-rubber instead of standard asphalt cement.

G. Modified Marshall or Hveem mixture design procedures are applicable to asphalt-rubber hot mixes.

In general, asphalt-rubber hot mixes may contain substantially increased binder contents than normally expected with standard mixes. Because of the resilient nature of the binder and the shear susceptibility characteristics, the asphalt-rubber hot mix may exhibit significantly higher flows in the Marshall evaluation and reduced stability in the Hveem evaluation.

For detailed mix design procedures and background design rational refer to the report entitled "Design Methods for Hot-Mixed Asphalt-Rubber Concrete Paving Materials" authored by James G. Chehovits and published in the proceedings of the National Seminar on Asphalt-Rubber, Kansas City, Missouri, October, 1989. This report is available from the Asphalt-Rubber Producers Group or from International Surfacing, Inc. For open-graded mixtures, the recommended design procedure is as outlined in the FHWA Report No. FHWA-RD-74-2 entitled "Design of Open-Graded Asphalt Friction Courses".

H. Selected whether cracks should be cleaned or routed. If there are a large number of cracks it may be more cost effective to seal the cracks with a slurry seal or tight blade.

I. Tack coat may be either an asphalt cement or diluted emulsified asphalt which is typical of that used in the area. Consideration should be given to elimination of the tack coat if the pavement being overlaid has excess free surface asphalt or if the pavement is being constructed on a new asphalt concrete surface.

Revised September 19, 1990
J. Mixture temperature should be as follows:

   - Open-graded: 275 to 325 degrees F
   - Dense-graded: 290 to 325 degrees F
   - Gap-graded: 290 to 325 degrees F

K. Mixture spread temperature shall be as follows:

   - Open-graded: 250 to 300 degrees F
   - Dense-graded: 275 to 300 degrees F
   - Gap-graded: 275 to 300 degrees F

L. Breakdown compaction shall consist of at least 3 full coverages for dense-graded or gap-graded mixtures and at least 2 full coverages for open-graded mixtures.

   With some asphalt-rubber mixtures, rolling may need to be delayed for several minutes after laydown to reduce shoving and displacement.

   Use of vibratory rollers is recommended for at least the first breakdown coverage for dense and gap-graded mixtures of 1-inch or greater thickness, but shall not be used for open-graded mixtures. On many mixes, the use of vibratory mode for breakdown rolling will provide improved compaction without problems normally experienced with standard asphalt concrete.

   Rolling should achieve at least 95% of the design density of dense-graded and gap-graded mixtures. Requirements for sampling and testing of density may be incorporated into this section.

M. A contingent bid item for anti-strip should be allowed for and be paid for by the pound of anti-strip additive used.
APPENDIX C
SPECIAL PROVISIONS FOR RUBBER MODIFIED ASPHALT

CONCRETE PAVEMENT

August 1990

SECTION 403 - ASPHALT PAVEMENT

Rubber modified asphalt concrete pavement shall be constructed in conformance with Section 403 of the Supplemental Standard Specifications, dated September, 1989, supplemented and/or modified as follows:

403.01 Scope - Delete this subsection on page 1 and substitute the following:

This work consists of construction one or more courses of rubber modified asphalt concrete (RUMAC) pavement plant mixed into a uniformly coated mass, which is a mixture of mineral aggregate, asphalt cement and granulated whole used tire rubber, hot laid on prepared foundation, compacted to specified density, and finished to a specified smoothness to the lines, grades, thickness and cross sections shown on the plans or as established by the Engineer.

403.02 Definitions and Abbreviations

(a) Definitions: Add the following definition to this subsection:

Rubber Modified Asphalt Concrete - A hot mixture of asphalt cement, graded aggregate, mineral filler, granulated whole used tire rubber and additives as required.

(b) Abbreviations - Add the following abbreviation to this subsection:

RUMAC - Rubber Modified Asphalt Concrete

Materials

403.11 Asphalt Cement, Additives, Mineral Filler And Aggregate Treatment

Delete this subsection heading on page 6 and substitute the following heading:

Asphalt cement, additives, mineral filler aggregate treatment and granulated whole used tire rubber.
Add the following to subsection 403.11:

(e) Granulated whole used tire rubber.

The granulated rubber shall be ambient ground from whole passenger and/or light truck tires. Truck tires and heavy equipment tires shall not be used. Rubber tire buffings from tire manufacture may not be used as supplement to the granulated rubber mixture. The rubber granulate shall be processed by ambient granulation to maintain the structural integrity and maximum solid (non-porous) surface area.

The ground tire rubber shall be cubical in shape and individual particles shall not be greater than 3/16 inches in length. The granulated rubber shall be free of wire and fabric balls or other foreign contaminating materials (fuzz). The rubber shall be dry with a moisture content of less that 0.75%. The specific gravity of the rubber shall be 1.15 ± 0.05. Granulated used tire rubber shall be packaged in low density polyethylene sacks having a melting point less than 240°F and loaded to a maximum weight of 80 pounds per sack when using a batch plant. For production of rubber modified asphalt concrete at a plant employing a drum, the rubber may be shipped and received in bulk, (ie tote containers) to a maximum per container of 200 pounds.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing (by weight)</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>100</td>
<td>± 5</td>
</tr>
<tr>
<td>No. 8</td>
<td>70</td>
<td>± 5</td>
</tr>
<tr>
<td>No. 10</td>
<td>55</td>
<td>± 5</td>
</tr>
<tr>
<td>No. 20</td>
<td>20</td>
<td>± 5</td>
</tr>
<tr>
<td>No. 40</td>
<td>10</td>
<td>± 5</td>
</tr>
</tbody>
</table>

The following chemical analysis shall apply to the rubber granulate:

- Specific Gravity: 1.15 ± 0.05
- Percent of Carbon Black: 35.0 MAX.
- Percent of Ash: 8.0 MAX.
- Percent of Acetone Extract: 12.0 MAX.

The rubber granulator (processor) shall furnish a written certification of compliance with the foregoing specifications.

Further, if state reimbursement funds for used tire recycling are to be applied for and used, the granulator (processor) shall furnish a written certification of used tire origin, acceptable to the DEQ's administrator of the used tire reimbursement program.
(a) **JMF For Rubber Modified Asphalt Concrete** - After a representative quantity of aggregate has been produced and not less than thirty (30) calendar days before production of the rubber modified asphalt concrete mix begins, the contractor shall furnish representative samples of material to be used in the mixture on the project to the project manager as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Aggregate</td>
<td>250 pounds of each size</td>
</tr>
<tr>
<td>Reclaimed (RUMAC)</td>
<td>200 pounds from each stockpile</td>
</tr>
<tr>
<td>Granulated Whole Used Tire Rubber</td>
<td>60 pounds</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td>20 pounds</td>
</tr>
<tr>
<td>Mineral Filler</td>
<td>20 pounds</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>2 gallons in one quart containers</td>
</tr>
<tr>
<td>Antistripping Additive</td>
<td>1 pint</td>
</tr>
</tbody>
</table>

The thirty (30) calendar day period will begin when samples of all materials, complying with the specifications, have been received by the project engineer or material laboratory as directed by the project engineer. The road agency will provide one JMF for each class of mix specified, at no cost to the contractor. The cost of development of any additional JMF requested by the contractor will be borne by the contractor.

(b) **Granulated Whole Used Tire Rubber Content** - The granulated whole used tire rubber percentage shall be two percent (2%) of total mix, with the tolerance range of ± 0.20%. (2% ± 0.02%)

### 403.15 Process Control

Add the following to this subsection:

(d) **Granulated Whole Used Tire Rubber** - The granulated whole used tire rubber shall be tested for sieve analysis and moisture content at the start of production and every 500 tons of production thereafter.

### Equipment

### 403.21 Asphalt Concrete Mixing Plant

Add the following to this subsection:
(p) Rubber Modified Asphalt Concrete Mixing Plant - The type of plant used for the manufacture of bituminous mixtures may be either a batch or drum mix plant. Mixing plants shall conform to the requirement of subsection 403.21, except the following shall be added:

1. Requirements for Batch Plants:

The amount of granulated rubber shall be determined by weighing on springless dial scales, or by a method which uniformly feeds the mixer within plus or minus 0.20 percent of the required amount as indicated in the above section.

2. Requirements for Drum Mixing Plants:

Granulated rubber introduced into the mixer shall be drawn from storage bins by a continuous mechanical feeder which will uniformly feed the mixer within plus or minus 0.20 percent of the required amount as indicated in the above sections.

The continuous feed system shall have a ready means of accurately calibrating the system.

Satisfactory means shall be provided to have a positive interlocking control between the flow of the granulated rubber and aggregates.

The rubber cannot be introduced with the cold aggregates. Objectional pollutants are produced if contact is made with the dryer flame, granulated rubber must be introduced beyond the flame. Rubber addition using a center entry recycle system is recommended.

The mixture adheres to rubber items, therefore, conveyance on rubber belts is prohibited.

403.22 Hauling Equipment

Delete subsection 403.22 (d) and substitute the following:

(d) Coat the beds with wetting agents such as soap. Do not use diesel oil, unless approved in writing by the project engineer.

403.24 Compactors

Delete the current subsection and substitute the following:

The contractor shall provide steel wheeled rollers and vibratory rollers capable of reversing without backlash as specified.
APPENDIX D
# Mix Design Data Summary

## Aggregate

<table>
<thead>
<tr>
<th>Material</th>
<th>Source</th>
<th>Designation</th>
<th>% Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregate</td>
<td>R L Houck</td>
<td>3/4&quot; to 1/4&quot;</td>
<td>30</td>
</tr>
<tr>
<td>Intermediate Aggregate</td>
<td>&quot;</td>
<td>1/4&quot; to #10</td>
<td>35</td>
</tr>
<tr>
<td>Crushed fines</td>
<td>&quot;</td>
<td>Sand</td>
<td>35</td>
</tr>
</tbody>
</table>

## Gradation Analysis

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Blend %</th>
<th>30</th>
<th>35</th>
<th>35</th>
<th>4</th>
<th>Job Mix Formula</th>
<th>Specification Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td></td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>98.2</td>
<td>100</td>
<td>100</td>
<td>99.6</td>
<td></td>
<td>95-100</td>
<td></td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>65.7</td>
<td>100</td>
<td>100</td>
<td>89.7</td>
<td></td>
<td>81-93</td>
<td></td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>6.1</td>
<td>90.5</td>
<td>100</td>
<td>68.6</td>
<td></td>
<td>52-72</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td>0.6</td>
<td>2.4</td>
<td>86.7</td>
<td>31.3</td>
<td></td>
<td>21-41</td>
<td></td>
</tr>
<tr>
<td>#40</td>
<td>0.3</td>
<td>1.0</td>
<td>36.2</td>
<td>13.1</td>
<td></td>
<td>8-24</td>
<td></td>
</tr>
<tr>
<td>#200</td>
<td>0.2</td>
<td>0.8</td>
<td>17.5</td>
<td>6.5</td>
<td></td>
<td>2-7</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bulk Sp. Gr.</th>
<th>2.7500</th>
<th>2.7134</th>
<th>2.6281</th>
<th>2.7023</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Sp. Gr.</td>
<td>2.8484</td>
<td>2.8442</td>
<td>2.8433</td>
<td>2.8452</td>
</tr>
</tbody>
</table>

% Absorption | 1.3 | 1.7 | 2.9 | 1.7 |
Material: Asphalt rubber dense graded binder

Identification: Chevron AC 5 @ 84% and Atlas 17100 @ 16% for Jackson Oregon

Source: Lab Stock

Sampled By: ___________________________ Date: ___________ Tested By: Paul Petroff

Requested By: Paul Oliver Date: ___________ Reviewed By: ___________

Test Procedure: Standard 24 hr Reaction

<table>
<thead>
<tr>
<th>TEST PERFORMED</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>6 hr</th>
<th>24 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, Haake at °F</td>
<td>1200</td>
<td>2200</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>Penetration, Cone @ 77° F in 1/10 mm</td>
<td></td>
<td></td>
<td>80</td>
<td>74</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Resilience @ 77° F in % rebound</td>
<td></td>
<td></td>
<td>23</td>
<td>24</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Ductility @ 77° F in cm pulled @ failure @ 5 cm/min.</td>
<td></td>
<td></td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softening Point in °F</td>
<td>122</td>
<td>128</td>
<td>130</td>
<td>129</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Fracture Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>°F Lowest Passing</td>
<td></td>
<td></td>
<td>26</td>
<td>24</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>°F Fracture</td>
<td></td>
<td></td>
<td>24</td>
<td>22</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

Asphalt Penetration @ 77° F was 99

Asphalt Softening Point was 115° F
### Mixture Design Data Summary

<table>
<thead>
<tr>
<th>binder</th>
<th>bulk</th>
<th>max.</th>
<th>density</th>
<th>air voids</th>
<th>vma</th>
<th>effective binder</th>
<th>stability</th>
<th>flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>2.2703</td>
<td>2.4736</td>
<td>141.7</td>
<td>8.2</td>
<td>21.2</td>
<td>6.0</td>
<td>1721</td>
<td>17</td>
</tr>
<tr>
<td>1.0</td>
<td>2.2623</td>
<td>2.4466</td>
<td>141.2</td>
<td>7.5</td>
<td>22.1</td>
<td>6.7</td>
<td>1383</td>
<td>21</td>
</tr>
<tr>
<td>7.75</td>
<td>2.2724</td>
<td>2.4202</td>
<td>141.8</td>
<td>6.1</td>
<td>22.4</td>
<td>7.5</td>
<td>1284</td>
<td>30</td>
</tr>
</tbody>
</table>

**Note:** Binder content is by total mixture weight.

**OTES:** Asphalt rubber reaction is on report I-89-170 and consists of Witco AC 5 Asphalt and 16% Atlas 1710C Rubber.

Compaction is 50/50 blow @ 275°F.
MIXTURE DESIGN DATA FLOTS

PROJECT Jackson County
DATE 7/20/89

BINDER CONTENT, % (MIX BASIS)

DENSITY (pcf)

BINDER CONTENT, % (MIX BASIS)

AIR Voids %

MARSHALL STABILITY (1000 lbs.)

MARSHALL FLOW (1/100 in.)
2.1 Asphalt Rubber

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Result</th>
<th>Specification Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, 350°F</td>
<td>3000</td>
<td>1500-4000</td>
</tr>
<tr>
<td>Cone Penetration</td>
<td>80</td>
<td>20 min</td>
</tr>
<tr>
<td>Softening Point</td>
<td>129</td>
<td>125°F</td>
</tr>
<tr>
<td>Resilience, 60 sec recovery; %</td>
<td>23</td>
<td>15% min</td>
</tr>
</tbody>
</table>

2.2 Reacted Properties

| Reaction Temperature | 350 | |
| Reaction Period      | 2 hrs | |

Laboratory Mixture Fabrication

| Mixing Temperature | 300°F | |
| Compaction Temperature | 275°F  | |
| Compaction Effort    | 50 blows per side | |

Design Binder Content
(by total mix weight) 7.75% - 8.0%
(by aggregate weight) 8.4% - 8.7%

Recommended Mix Temperature 300°F - 325°F

Minimum Laydown Temperature 280°F

Laboratory Density at Design Binder Content 141.8 PCF

Field Compacted Density 136.9 PCF min.
July 27, 1990

Project #2210

Attn: Gene Morris


Introduction

The scope of this project was to develop a Marshall Mix Design (75 blows) on an asphalt-rubber concrete mixture. Certain modifications in the normal mix design method were used as recommended in Appendix F of the contract specifications. Compaction temperature was one such example. Test specimens were compacted at 280°F after curing at that temperature for 2 hours per specification method.

Asphalt-Rubber Properties

The original asphalt cement was an AC-5 supplied by Idaho Asphalt Supply from their Post Falls, ID plant. The specific gravity was reported to be 1.040. A ground rubber product was blended with this asphalt at 16% by total weight of asphalt-rubber binder, no extender oil was needed. The temperature range, reaction time and viscosity range specified in Appendix F of the contract were observed. The ground rubber specific gravity was assumed to be 1.175 with the final asphalt-rubber specific gravity calculated at 1.059 for mix design purposes.

Aggregate Properties

The stockpile samples and gradation averages were supplied by Shamrock Paving. The two stockpiles include a 5/8"-1/4" chips and 3/8"-0 stockpile. The properties of the combined aggregate are shown in Table I. The stockpiles were separated by sieve sizes and re-combined to fit the Job Mix Formula.
Marshall Mix Data

The data obtained from the Marshall Mix Design Method are shown in Tables II and III and Figures 1 through 8. The samples were compacted with 75 blows per side at 280°F after curing at 280°F for 2 hours. The asphalt-rubber content selected as optimum is 8.2% based on mix = 100%. The properties of the mix at 8.2% asphalt are shown in Table III. The results of the Modified Lottman Test are outlined at the bottom of Table II. No anti-stripping agent will be required.

An additional note is needed regarding the field application of this mix design. In this project the contractor will be required to compact to 95% of the theoretical maximum density, 3% less air voids than is usually required. The actual range of asphalt-rubber content that meets mix design criteria is 7.7% to 8.6%, using 3-5% air voids. (Appendix F suggested that 3-4% air voids might be a better criteria so 8.2% asphalt-rubber was selected because it falls just below 4% air voids). If problems arise in consistently meeting the 95% compaction standard the option of raising the asphalt-rubber content (to no higher than 8.6%) should be considered. This would not conflict with the mix design criteria. If this option is pursued, Figure 5 in our mix design provides a chart from which the Theoretical Maximum Density can be plotted at various asphalt-rubber contents.

Kent Henderson, AET (NICET)
Technical Service

Robert L Dunning, M.S.
Consulting Chemist
### Table I

**Aggregate Properties**

**Gradations by % passing**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>5/8-1/4&quot; Chips</th>
<th>3/8&quot;-0 Stockpile</th>
<th>Blend</th>
<th>Page 25 1/2&quot;-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100</td>
</tr>
<tr>
<td>1/2</td>
<td>90.0</td>
<td>100.0</td>
<td>96.0</td>
<td>90-100</td>
</tr>
<tr>
<td>3/8</td>
<td>35.0</td>
<td>99.0</td>
<td>73.4</td>
<td>70-90</td>
</tr>
<tr>
<td>1/4</td>
<td>5.0</td>
<td>86.0</td>
<td>53.6</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>3.0</td>
<td>76.0</td>
<td>46.8</td>
<td>35-50</td>
</tr>
<tr>
<td>8</td>
<td>2.0</td>
<td>50.5</td>
<td>31.1</td>
<td>20-32</td>
</tr>
<tr>
<td>30</td>
<td>1.0</td>
<td>24.0</td>
<td>14.8</td>
<td>8-18</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
<td>16.0</td>
<td>10.0</td>
<td>5-14</td>
</tr>
<tr>
<td>200</td>
<td>1.0</td>
<td>8.0</td>
<td>5.2</td>
<td>2-6</td>
</tr>
</tbody>
</table>

**Percentage**

| 40 | 60 |

**Specific Gravities**

<table>
<thead>
<tr>
<th></th>
<th>Coarse</th>
<th>Fine</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk</td>
<td>2.728</td>
<td>2.559</td>
<td>2.646</td>
</tr>
<tr>
<td>Bulk, SSD</td>
<td>2.781</td>
<td>2.650</td>
<td>2.718</td>
</tr>
<tr>
<td>Apparent</td>
<td>2.881</td>
<td>2.814</td>
<td>2.849</td>
</tr>
<tr>
<td>Absorption</td>
<td>1.94</td>
<td>3.54</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Effective, based on Agg. 2.810
# TABLE II

**Marshall Mix Data**

<table>
<thead>
<tr>
<th>% ASPHALT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>on Aggregate</td>
<td>7.53</td>
<td>8.11</td>
<td>8.70</td>
<td>9.29</td>
<td>9.89</td>
</tr>
<tr>
<td>on Mix total</td>
<td>7.0</td>
<td>7.5</td>
<td>8.0</td>
<td>8.5</td>
<td>9.0</td>
</tr>
<tr>
<td>absorption</td>
<td>2.54</td>
<td>2.18</td>
<td>2.29</td>
<td>2.31</td>
<td>2.27</td>
</tr>
<tr>
<td>effective</td>
<td>4.63</td>
<td>5.49</td>
<td>5.89</td>
<td>6.38</td>
<td>6.93</td>
</tr>
</tbody>
</table>

**SPECIFIC GRAVITIES**

<table>
<thead>
<tr>
<th>Bulk unit wt., pcf</th>
<th>2.370</th>
<th>2.364</th>
<th>2.365</th>
<th>2.382</th>
<th>2.388</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Maximum unit wt., pcf</td>
<td>147.9</td>
<td>147.5</td>
<td>147.6</td>
<td>148.6</td>
<td>149.0</td>
</tr>
<tr>
<td>Effective of Agg.</td>
<td>2.529</td>
<td>2.490</td>
<td>2.470</td>
<td>2.461</td>
<td>2.441</td>
</tr>
<tr>
<td>unit wt., pcf</td>
<td>157.8</td>
<td>155.4</td>
<td>154.6</td>
<td>153.6</td>
<td>152.3</td>
</tr>
<tr>
<td>Effective of Agg.</td>
<td>2.827</td>
<td>2.799</td>
<td>2.808</td>
<td>2.809</td>
<td>2.806</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Voids, % Mineral Agg</th>
<th>16.7</th>
<th>17.4</th>
<th>17.8</th>
<th>17.6</th>
<th>17.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Air Voids</td>
<td>6.3</td>
<td>5.1</td>
<td>4.6</td>
<td>3.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Filled, (COE method)</td>
<td>71</td>
<td>77</td>
<td>80</td>
<td>86</td>
<td>90</td>
</tr>
</tbody>
</table>

**MARSHALL DATA**

| Stability, lbs | 2237 | 2125 | 2153 | 2400 | 2210 |
| Flow, in/100 | 13.5 | 14.5 | 13   | 16   | 17.5 |

**MODIFIED LOTTHAN TEST**

<table>
<thead>
<tr>
<th>% Anti-Strip, Pavement Bond, AP</th>
<th>Indirect Tensile Strength, lbs.</th>
<th>% Retained Strength</th>
<th>Stripping</th>
<th>Air Voids</th>
</tr>
</thead>
<tbody>
<tr>
<td>0, control</td>
<td>875</td>
<td>(100)</td>
<td>none</td>
<td>6.5</td>
</tr>
<tr>
<td>0, test</td>
<td>755</td>
<td>86.3</td>
<td>none</td>
<td>5.9</td>
</tr>
<tr>
<td>0.5</td>
<td>705</td>
<td>80.5</td>
<td>none</td>
<td>6.7</td>
</tr>
<tr>
<td>1.0</td>
<td>675</td>
<td>77.1</td>
<td>none</td>
<td>7.0</td>
</tr>
</tbody>
</table>
### Table III
Properties at Optimum Asphalt Content

<table>
<thead>
<tr>
<th>Specification</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Asphalt-Rubber</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on mix</td>
<td>8.2</td>
<td>-</td>
</tr>
<tr>
<td>effective</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>Marshall Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>2300</td>
<td>500 min.</td>
</tr>
<tr>
<td>Flow, in/100</td>
<td>15</td>
<td>8-22</td>
</tr>
<tr>
<td>Percent Voids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on mix</td>
<td>3.9</td>
<td>3-5 (4)</td>
</tr>
<tr>
<td>VMA</td>
<td>17.5</td>
<td></td>
</tr>
<tr>
<td>Filled with Asphalt</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Unit wts., pcf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bulk</td>
<td>148.2</td>
<td></td>
</tr>
<tr>
<td>max. theoretical</td>
<td>154.2</td>
<td></td>
</tr>
</tbody>
</table>
Alternate Table III
Properties at 8.5% Asphalt-Rubber Content

<table>
<thead>
<tr>
<th>% Asphalt-Rubber</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>on mix</td>
<td>8.5</td>
</tr>
<tr>
<td>effective</td>
<td>6.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Marshall Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>2310</td>
</tr>
<tr>
<td>Flow, in/100</td>
<td>15.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percent Voids</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>on mix</td>
<td>3.2</td>
</tr>
<tr>
<td>VMA</td>
<td>17.7</td>
</tr>
<tr>
<td>Filled with Asphalt</td>
<td>86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit wts., pcf</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>bulk</td>
<td>148.5</td>
</tr>
<tr>
<td>max. theoretical</td>
<td>153.5</td>
</tr>
</tbody>
</table>
Figure 1

Air Voids

Figure 2

Laboratory Compacted Density
Figure 3

Marshall Stability

Figure 4

Plastic Flow, Marshall Method
Figure 5

Max. Theoretical Density/ASTM D-2041

Figure 6

Voids in the Mineral Aggregate
Effective Asphalt Content

Figure 7

Voids Filled with Asphalt

Figure 8
International Surfacing #2210
NW Blvd. Resurfacing Project.

GRADATION CHART
SIEVE SIZES RAISED TO 0.45 POWER

A THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

- Specification
- Job Mix Formula

Petroleum Sciences
APPENDIX F
August 27, 1990

Mr. Robert Raynes
Morse Brothers Construction
P.O. Box 1126
Corvallis OR 97339

RE: Rubber Modified Asphalt Concrete Mix Design (PlusRide) for the Benton County Projects

Dear Mr. Raynes,

As per your request, we have performed a Marshall Mix Design for rubber modified asphalt concrete (PlusRide), for Benton County overlay projects (Alpine cut off road project No. 45122-01-88, and Evergreen Road project No. 26290-01-88). The testing was performed essentially in accordance with the Asphalt Institute (MS-2), current edition, AASHTO Methods of sampling and testing.

The aggregate and hot bins aggregate gradations were supplied by Morse Brothers Construction. The aggregate was separated and blended to obtain the indicated Job Mix Formula (JMF). It should be noted that the cold feed aggregate at the mixing plant may vary from the design stockpile gradation. Therefore, adjustments, and calibrations may be needed based upon moisture content, and/or gradation variations.

The optimum asphalt content was based upon the average percent air void, resilient modulus, permanent deformation, and fatigue life; and was determined to be 7.9 percent by total weight of the mixture.

If you have any questions concerning the results, procedures, or if we can be of any further assistance, please call on us at (714) 833 - 9867. I am looking forward to working with you on this project.

Respectfully submitted,

BAS Corporation

H. B. Takallou, Ph.D., P.E.
Pavement Engineer
Marshall Job Mix Formula

Prepared for:
Benton County Overlay Projects
Alpine cut off road overlay
Project No. 45122-01-88
Evergreen road overlay
Project No. 26290-01-88

Prepared by:
BAS Engineering
Suite 610
1920 Main Street
Irvine, Ca 92714
(714) 833 9867

Date:
August 27, 1990
Asphalt Cement:

- Asphalt cement content: 7.9% by weight of total mix (specs. 7.5% to 8.3%)
- McCall AC 20
- Tolerance ± 0.4 percent

Aggregate Gradation:

Hot Bins Aggregate Gradation, (provided by Morse Bros.)

<table>
<thead>
<tr>
<th>SIEVE SIZE</th>
<th>Bin No. 3</th>
<th>Bin No. 2</th>
<th>Bin No. 1</th>
<th>Filler Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/8 in.</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1/2 in.</td>
<td>93</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>52</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1/4 in.</td>
<td>9</td>
<td>80</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No. 10</td>
<td>2</td>
<td>6</td>
<td>82</td>
<td>100</td>
</tr>
<tr>
<td>No. 30</td>
<td>2</td>
<td>1</td>
<td>38</td>
<td>100</td>
</tr>
<tr>
<td>No. 40</td>
<td>2</td>
<td>1</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>No. 200</td>
<td>1.3</td>
<td>0.3</td>
<td>11.7</td>
<td>100</td>
</tr>
</tbody>
</table>
### Aggregate Blending:

- 68 percent Bin #3 (1/2 - 1/4)
- 27 percent Bin #1 (No. 10 - 0)
- 5 percent Filler (cement)

### Blended Aggregate Gradation:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing by Weight</th>
<th>Combined Grading Limit</th>
<th>Specification Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/8 in.</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1/2 in.</td>
<td>95</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>67</td>
<td>60 - 80</td>
<td>60 - 80</td>
</tr>
<tr>
<td>1/4 in.</td>
<td>38</td>
<td>30 - 44</td>
<td>30 - 44</td>
</tr>
<tr>
<td>No. 10</td>
<td>28.5</td>
<td>20 - 32</td>
<td>20 - 32</td>
</tr>
<tr>
<td>No. 30</td>
<td>16.6</td>
<td>13 - 25</td>
<td>13 - 25</td>
</tr>
<tr>
<td>No. 200</td>
<td>9.0</td>
<td>9 -12</td>
<td>9 -12</td>
</tr>
</tbody>
</table>

### Granulated Tire Rubber Content:

- 3.0 percent by weight of Total Mix

**Specification Limits**: 2.85% - 3.15% (Tolerance ± 0.15%)

### Rubber Gradation:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 in.</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>76 - 100</td>
</tr>
<tr>
<td>No. 10</td>
<td>28 - 42</td>
</tr>
<tr>
<td>No. 20</td>
<td>16 - 24</td>
</tr>
</tbody>
</table>
Construction Notes:

Mixing Temperature:

-- Aggregate 340°F (300°F - 380°F)
-- Discharge Temperature 320°F (300°F - 340°F)

Compaction Temperature:

-- Breakdown Temperature 280°F (270°F - 290°F)

Target Density - Minimum, 95% of maximum Theoretical Density

Batch Weights:
Assume 1 Ton Batch

-- Bin Number 3 1,212.0 lbs.
-- Bin Number 1 481.0 lbs.
-- Filler (cement) 89.0 lbs.
-- Rubber 60.0 lbs.
-- Asphalt cement 158.0 lbs.

2,000.0 lbs.
BIBLIOGRAPHY

(1) Takallou, H.B. and R.G. Hicks, "Crumb Rubber as an Additive to Asphalt Concrete: A Possible Solution to the Waste Tire Problem", Presentation at the DEQ/METRO Demonstration Paving Project Workshop, June 29, 1990.

(2) "Developing Issues", Asphalt Technology News, Volume 2, Number 1, Spring 1990.


(8) Trunk, J., Inspection of Evergreen Road and Alpine Cutoff Road, FHWA Region 10, September 21, 1990.


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(11) Linn County, Interview and project information, June 7, 1990.

(12) Petrasck, D., Jackson County Engineer, Telephone conversation on October 16, 1990.


(14) Dunning, B., Petroleum Sciences, Inc., Telephone conversation on 10/16/90.


(17) Hightower, P., Benton County Engineer, Interview and project information, September 21, 1990.