polymer or rubber-modified asphalt specifications.

(b) Torsional Recovery Test-Snyder et al (Ref. 5) report that this test measures the elasticity imparted by a polymer or rubber to the asphalt cement. A metal disc is embedded in asphalt or modified asphalt, rotated 180° relative to the sample container, the band is removed and the specimen is allowed to recover. Results are recorded after 30 seconds and 30 minutes. King et al (Ref. 13) calculate the percent recovery as:

\%
\text{Recovery} = \frac{A}{B} \times 100

A = \text{Arc length between recovery marks at 30 seconds and 30 minutes}

B = \text{Arc length for 180° rotation}

King et al further report that this test is used by the State of California as a standard (Test 332) for evaluating latex modified asphalt emulsion residues. King et al cite the following as limitations of the test: (1) lack of precise temperature control, (2) inability to apply a constant strain, (3) the sample is large requiring multiple emulsion evaporations, and (4) the instantaneous elastic recovery that occurs during the first thirty seconds after release is excluded from the recovery calculation.

However, the State of California uses this test as an indicator of the percent rubber that was added to the asphalt.

(c) ARRB Elastic Recovery Rheometer-The Australian Road Research Board developed a modified Shell sliding plate rheometer to study polymerized and rubberized bitumens (Ref. 21). The instrument measures creep during shear and elastic recovery after shear. The properties which are determined from test results include: instantaneous elastic strain, retarded elastic strain, equilibrium viscous flow, instantaneous elastic recovery, retarded elastic recovery, and permanent
set. Elastic recovery is calculated as:

\[
\text{Percentage Elastic Recovery} = \left(\frac{\text{RD}}{\text{OD}}\right) \times 100
\]

RD = Recovery Displacement
OD = Original Displacement

The material model used to establish the above results is a Maxwell element in series with a Voigt-Kelvin element resulting in a four parameter model.

(d) Dekker Elastic Recovery Device- This device was developed by Dekker in the Terahute Laboratories of Elf Aquitaine to measure the time dependent creep response or theological properties of polymer modified asphalts. A second generation model was recently presented by Dekker at the Laramie Annual Asphalt Research Meeting in July 1987.

Conclusions

From the preceding discussion of tests the following properties appear to offer potential for use in developing specification tests for asphalt-rubber mixtures.

- Viscosity (Brookfield or Haake).
- Modified or standard softening point.
- Force ductility compliance values. If a modified ductility bath is not available standard ductility values at 39.2°F can be used, however, use of that test was not discussed in this report.
- Schweyer measurements of shear susceptibility and low temperature viscosity at a constant power of 100 watts/m³.
• Toughness/tenacity. In conjunction with low temperature ductility these properties contribute to aggregate retention and improved low temperature properties, and
• Gradation analysis. This test is necessary to determine particle size before incorporation of rubber particles in the asphalt.

Until a proper test and the expected range of test values is established, it is recommended that the amounts of actual rubber and asphalt cement used at the HMA plant be monitored so that the percentage of rubber by weight of the binder can be calculated on a daily basis. Extensive testing of asphalt-rubber blends employing various proposed test methods will be necessary in order to select and adopt an appropriate test method and to define a range of acceptable test values.

**Subtask 1e.**

Determine the range of the amount of ground tire rubber which could be incorporated into the asphalt without a detrimental effect on mix properties of FDOT FC-1, FC-4 and FC-2 mixtures.

This section addresses the amount of ground tire rubber that can be added to FC-1, FC-2, and FC-4 mixes without adversely affecting the quality of the mixture. All mixes react differently to additives and hence it is not possible to describe the effect of adding ground rubber for all mixes but anticipated results for typical mixtures are discussed.

Most research has been performed using relatively high amounts of rubber and hence little information is available at low rubber contents. Lundy (Ref. 20) and others studied the use of 3 to 4 percent (by weight of aggregate) reclaimed rubber in Oregon. The trade mark for the process they evaluated is PlusRide. In this process the rubber particles are large (1/16 - 1/4 in.) and
replace some of the aggregate. The rubber is approximately equal to 30% of the asphalt binder by weight. The rubber is premixed with the aggregate prior to adding the asphalt. After evaluating the relative performance of a control strip and a PlusRide section for 3 years, the authors concluded that there was no significant difference in performance between the PlusRide and conventional asphalt mix.

A laboratory study by Lalwani and others (Ref. 21) investigated the effect of the amount of reclaimed rubber on the combined properties of asphalt-rubber. Their study included the addition of 0, 7.5, 15, and 30 percent rubber to a 60/70 penetration asphalt. They concluded that to significantly change the binder properties at least 20% rubber had to be added to the asphalt. The rubber and asphalt were blended at a temperature of 200°C (392°F). They recommended that the ideal rubber particle size was 300 (No. 50 sieve) to 600 (No. 30 sieve) microns.

Laboratory tests by Piggott and others (Ref. 22) showed that the addition of 5% rubber by weight of the total binder would increase the asphalt viscosity at 95°C by 10-50 percent. Their work also showed that 20% rubber would decrease the Marshall stability by approximately 50%.

The FDOT is scheduled to build a number of asphalt-rubber test sections in 1989. These sections will be monitored for a period of time to evaluate short term performance. It is expected that modifications to the existing specifications on asphalt-rubber will be made at various points throughout the evaluation period.

Since the compatibility of the recycling process and asphalt rubber reaction process is unknown, FDOT should initially use the asphalt-rubber in virgin mixes only. At the present time FDOT does not use RAP material in its friction course mixes FC-1, FC-2, and FC-4. Hence these mixes were evaluated for potential of using reclaimed rubber. The specified requirements for these three
mixtures are presented in Table 6.

Even though the minimum VMA specified for mixes FC-1 and FC-4 is 15, it is unlikely that the actual VMA for FC-1 mix will be below 20 percent and it is also unlikely that the VMA for FC-4 mix will be less than 22. These values were determined from the minimum void requirement and the minimum allowable asphalt content. The VMA of FC-2 mix is likely to be greater than 30. These high VMA values should minimize the effect of adding rubber to the asphalt mixture.

There are a number of concerns that have to be considered when using reclaimed rubber: air pollution, workability, compaction, surface texture, long term performance, etc. Because of these concerns, initial requirements for the amount of rubber to be used in the mixture should be on the conservative side. It is thus recommended that the initial maximum rubber added for FC-1 and FC-4 mixes be 5 percent by weight of total binder. Higher rubber contents may prove to perform very well, but additional experience is needed before using these higher contents. Since the same amount of effort is required to add the rubber it is recommended that at least 3 percent be used to make the addition worthwhile.

Since the VMA of FC-2 mix is larger than that of the FC-1 and FC-4 mixes, FC-2 should be able to use more rubber without detrimental effects to the mix. It is recommended that the rubber in the FC-2 mix be increased to 10 percent by weight of total binder.

As stated earlier there is not much information in the literature to provide guidance on how much rubber to use in a mix. The amounts recommended in this section were selected based on the small amount of information available and on the experience of the authors. When additional construction and performance information is developed from the FDOT test sections, the recommended amounts will likely be modified. AU things considered, it is best to start
<table>
<thead>
<tr>
<th>Property</th>
<th>Mixture Decimation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FC-1</td>
</tr>
<tr>
<td>Gradation Sieve Size</td>
<td></td>
</tr>
<tr>
<td>1/2 inch</td>
<td>100</td>
</tr>
<tr>
<td>3/8 inch</td>
<td>***</td>
</tr>
<tr>
<td>No. 4</td>
<td>***</td>
</tr>
<tr>
<td>No. 10</td>
<td>55-85</td>
</tr>
<tr>
<td>No. 40</td>
<td>***</td>
</tr>
<tr>
<td>No. 80</td>
<td>***</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-8</td>
</tr>
<tr>
<td>Minimum Stability (lbs)</td>
<td>500</td>
</tr>
<tr>
<td>Flow (.01 inches)</td>
<td>8-16</td>
</tr>
<tr>
<td>Minimum VMA (%)</td>
<td>15</td>
</tr>
<tr>
<td>Air Voids (%)</td>
<td>8-14</td>
</tr>
<tr>
<td>Minimum Eff. Asphalt Content (%)</td>
<td>5.5</td>
</tr>
</tbody>
</table>
conservatively when evaluating a new product.

Subtask If.

Identify and justify any changes in mix design specification and procedures for mixtures FC-1, FC-4, and FC-2 when asphalt is modified with ground tire rubber.

Before proposing necessary changes to specifications and procedures the background information on asphalt-rubber blends is discussed first.

Consistency of Asphalt-Rubber Blends

Factors which affect consistency of asphalt-rubber are shown below:

- rubber content,
- rubber size (gradation),
- original asphalt viscosity,
- reaction conditions (temperature and time) and,
- temperature of asphalt-rubber after reaction.

Research indicates that the manner in which the above factors are combined determine the consistency of the final asphalt-rubber blend. The following discussion explains how each of the factors listed affects the consistency of the asphalt-rubber blends.

Rubber Content and Size
Research indicates that for a given asphalt-rubber binder consistency a relationship such as that shown in Figure 6 can be used to estimate approximate rubber concentration and size combinations (Ref. 3). For instance, 5% rubber of No. 100 sieve size should produce a viscosity similar to 22% rubber of No. 8 sieve size when added to a given asphalt cement.

The above superposition principle assumes one-size rubber particles. Because ground tire rubber is often graded, albeit, usually two or three sizes, the quantity of rubber to be added to an asphalt-rubber blend should be adjusted based on Figure 6 to account for the different sizes. The effect of amount of rubber on viscosity is shown in Figure 7 (Ref. 22).

To determine the percentage of a graded rubber product to be added to asphalt to produce asphalt-rubber, the following example is provided.

**Example to Determine Rubber Content.** Ground tire rubber is to be blended with asphalt cement to produce asphalt-rubber. The rubber comes packaged from the recycler in 50 pound bags. A sieve analysis conducted on the rubber using a modification of the ASTM D 136 procedure reveals the gradation shown below in Table 7. The amount of rubber required is then determined as shown in Table 7.

**Viscosity**

During the asphalt and rubber blending operation, consistency can be controlled by diluting the blend with petroleum distillates or aromatic extender oils. This may not be necessary for low rubber contents. The quantity and type of oil to be added varies depending on rubber size, quantity, asphalt source and grade, and reaction conditions. Aromatic oils found suitable for
Figure 6. Size/Concentration Superposition Relationship
Figure 7. Effect on the Viscosity of Asphalt-Cement of Adding Ground Vulcanized Reclaimed Rubber, and Screened Devulcanized Reclaimed Rubber
Table 7. Percentage of Graded Rubber Needed for Asphalt-Rubber Blend Example

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
<th>Fraction</th>
<th>Avg. Size</th>
<th>% Between</th>
<th>Recomm. Cone. %</th>
<th>% Required</th>
</tr>
</thead>
<tbody>
<tr>
<td># 16</td>
<td>100</td>
<td>16-40</td>
<td>28</td>
<td>10</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td># 40</td>
<td>90</td>
<td>16-40</td>
<td>28</td>
<td>10</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td># 80</td>
<td>15</td>
<td>40-80</td>
<td>60</td>
<td>75</td>
<td>9</td>
<td>6.8</td>
</tr>
<tr>
<td>#200</td>
<td>1</td>
<td>80-200</td>
<td>140</td>
<td>14</td>
<td>4</td>
<td>0.6</td>
</tr>
<tr>
<td>-200</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>4</td>
<td>0.0</td>
</tr>
</tbody>
</table>

8.9
adjusting viscosity include Sundex, Dutrex, and Califlux. The low levels of rubber as suggested in this report to be used by FDOT should not require aromatic oils except perhaps for the FC-2 mixes with 10% rubber. Another possible approach for lowering the viscosity is to use a lower viscosity grade asphalt instead of extender oil. However, this will result in a permanent reduction in viscosity.

**Reaction Conditions**

Asphalt cement and ground tire rubber are mixed together and blended at elevated temperatures for various periods of time prior to use as a paving binder. This variation in mixing time occurs because of the normal activities associated with asphalt paving construction. However, consistency of asphalt-rubber blends is affected by the time and temperature used to combine the components and must be carefully controlled if desirable results are to be achieved. In general, the consistency of asphalt-rubber is reduced as temperature and time are increased beyond the time required to produce the initial reaction between liquid asphalt and solid tire rubber. This initial reaction is not well understood, but appears to be due to a chemical and physical exchange between the asphalt and rubber particles in which the rubber swells in volume causing an increase in viscosity as shown in Figure 8 (Ref. 3).

The reaction is generally considered completed when the viscosity of the blend becomes relatively constant, as shown at approximately 100 minutes in Figure 8. Continued mixing of asphalt and rubber after this point can begin to reduce the consistency of the blend as the rubber particles break apart during mixing with the hot asphalt cement. However, breakdown of the rubber particles is not rapid, and may require several hours at high temperatures before noticeable loss in viscosity results.
Figure 8. Effect of Digestion Time on Viscosity of Asphalt-Rubber (Ref. 3)
Studies indicate that best results are obtained when asphalt-rubber is used as quickly as possible after blending. **Allowing** the asphalt-rubber blend to remain heated for long periods after mixing is not recommended because of reduced consistency which can occur. Blends have been allowed to cool in storage tanks and reheated prior to use without difficulty (Ref. 23).

To obtain workable asphalt-rubber in the field, the consistency of the asphalt-rubber blend is modified by adjusting the factors described above. No specific recipe can be described which provides the most desirable characteristics, therefore judgement of the engineer is critical when determining optimum combinations of components and blending techniques. However, viscosity within the limits specified has been used successfully on many projects to control consistency, and with experience a workable blend can be produced.

**Recommended Design Modifications**

Hot mix asphalt fabricated with asphalt-rubber binders will require certain changes in the mixture design process. The four elements to be discussed are as follows:

- Aggregate Type
- Aggregate Gradation
- Binder Characteristics
- Binder Content

**Aggregate Type**

Aggregates used in asphalt-rubber HMA should meet the same requirements as for high quality conventional HMA, that is, for soundness, durability, and crushed faces.
Aggregate Gradation

Asphalt-rubber can be prepared using various sizes of ground rubber. The consistency of the asphalt-rubber blend may vary significantly depending on the factors previously discussed to prepare the blend. However, at a given temperature asphalt-rubber binders generally have a much higher viscosity than conventional asphalt binders. This greater viscosity produces thicker asphalt-rubber films on the aggregate at a given mix temperature than for asphalt. Because of these thicker films and because some particulate, unreacted rubber maybe present, the aggregate gradation of asphalt mixtures produced using asphalt-rubber should be opened up to allow room for the binder. This may be particularly important for fine rubber gradings because swelling of the finer rubber in the presence of asphalt creates significant volume change in the rubber.

Figures 9 through 11 represent the gradations which potentially will be candidates for manufacture using asphalt-rubber binders. Each of the figures is presented with the grading bands specified by FDOT Specifications, Section 331, (Ref. 4).

Each of the figures includes the FHWA 0.45 power grading curve as a reference,

Gradations FG1 and FG4

Each of the gradations shown in Figures 9 and 10 produces a relatively fine textured mixture. Properties of these mixtures as described by FDOT in Table 331-2, (Table 6) of the Standard Specifications indicate that each has maximum air void contents of 14 and 16%, respectively, for the FC-1 and FC-4 mixes and both have a minimum VMA of 15%. As previously stated, each of these mixtures should be fabricated to provide room for thicker asphalt films when asphalt-rubber binders are utilized. Opening the grading to allow somewhat coarser mixtures and limiting the size
Figure 9. Florida FC-1 Grading (Dense Graded Friction Course)
Figure 10. Florida FC-4 Grading (Dense Graded Friction Course)
Figure 11. Florida FC-2 Grading (Open Graded Friction Course)
and quantity of rubber should help compensate for the high viscosity asphalt-rubber. Rubber sizes should be limited to material passing the No. 80 sieve for the FC-1 and FC-4 mixtures. Quantity of rubber should be limited to 3-5 percent by total binder weight until performance information can be gathered to support use of higher quantities.

**Gradation FC-2**

This open graded material consists of approximately one-size aggregate between the 3/8” and No. 10 sieves (Figure 11). Because of the open gradation sufficient room should exist for thick asphalt films created by asphalt-rubber binders. However, some cases of excessive ravening have occurred in mixtures of this type when mix design and construction procedures were not closely followed. In addition, large size and large quantities of rubber particles could lead to instability difficulties arising from incompatibility between elastic asphalt-rubber and non-elastic aggregates. Therefore, size and quantity of rubber should be carefully controlled to material passing the No. 24 sieve at levels of less than 10% by weight of total binder until performance information can be gathered to support use of higher quantities and/or different sizes.

**Binder Characteristics**

As stated previously, the consistency of the asphalt-rubber binders depend on several factors related to the binder constituents. However, certain properties have been published (Refs. 3, 24, 25) and summarized in Table 8 which should provide guidance when use of asphalt-rubber binders is anticipated. These values are for high rubber content (15-26%) and thus do not directly apply to the FDOT Specifications.
Table 8. Characteristics of Classical* Asphalt-Rubber Binders

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, 140°F, P, <em>(Brookfield)</em></td>
<td>700-60,000</td>
</tr>
<tr>
<td>Viscosity, 350°F, cP, <em>(Brookfield)</em></td>
<td>1500-4000</td>
</tr>
<tr>
<td>Softening Point, R &amp; B, F (ASTM D36), <strong>min</strong></td>
<td>115 (I); 130 (II)</td>
</tr>
<tr>
<td>Cone Penetration, 77°F, (ASTM D1191), <strong>min</strong></td>
<td>40 (I); 20 (II)</td>
</tr>
<tr>
<td>Resilience, 77°F (ASTM D3407), % <strong>min</strong></td>
<td>15</td>
</tr>
<tr>
<td>Modulus**, psi, 39.2F@</td>
<td></td>
</tr>
<tr>
<td>0.20 seconds loading</td>
<td>1,000-10,000</td>
</tr>
<tr>
<td>0.50 seconds loading</td>
<td>600-6,000</td>
</tr>
</tbody>
</table>

* Contains 15-26% #10-#50 rubber by wt binder *(Ref. 3, 23, 26)*

** Tensile Elongation @ 10%/min.
Binder Content

Asphalt concrete mixtures fabricated with asphalt-rubber require higher binder contents than mixtures fabricated with conventional paving grade asphalts. At least two reasons are cited for higher binder contents: (1) the asphalt-rubber is significantly more viscous than conventional binders, providing thicker film coatings on the aggregates, and (2) the unreacted rubber particles act as solid filler, increasing the binder volume but not necessarily binder adhesive characteristics.

Conventional mix design procedures should be used to determine optimum binder content for asphalt-rubber mixtures. However, criteria for establishing optimum binder content may require modification to account for the potentially elastomeric properties provided by the asphalt-rubber. For example, Marshall stability and flow could be expected to be lower and higher, respectively, due to the elastic nature and lower modulus of rubber modified binders. These effects should increase as the rubber content increases.

Changes to Table 331-2 of the Standard Specifications are reflected in Table 9 with respect to higher VMA and higher effective asphalt content, as previously discussed. In addition, maximum Marshall flow has been adjusted upward to account for potentially higher strain at failure due to the elastic characteristics of the asphalt-rubber binder. The change in VMA is academic since previous mixes had to have VMA above 17 to meet requirements for voids and minimum effective asphalt content.

Subtask Id.

Determine or verify the lab method of incorporation of rubber into asphalt so as to be representative of the field method of incorporation.
Table 9. Suggested **Marshall** Criteria for Hot Mix Asphalt

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Marshall Stability, min.</th>
<th>Flow, .01 in</th>
<th>VMA, %</th>
<th>Air Voids, %</th>
<th>Effective Binder, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-1</td>
<td>500</td>
<td>8-18</td>
<td>17</td>
<td>8-14</td>
<td>6.0</td>
</tr>
<tr>
<td>FC-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC-4</td>
<td>500</td>
<td>8-18</td>
<td>17</td>
<td>12-16</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Laboratory Preparation of Mixtures

Note: AU temperatures mentioned throughout this subtask are based on experience with high rubber contents (18-26% by weight of binder). It is likely that these temperatures can be lowered for 5-10% rubber. The temperatures specified for reacting liquid asphalt and rubber are likely to remain the same, however, the reaction time can probably be reduced because of the small amount of rubber and smaller rubber size.

Before mixtures of binder and aggregate can be prepared the asphalt-rubber must be blended and reacted. Shuler (Ref. 3, 23) has verified that if the blending is accomplished using specialized mixing equipment, the resulting mixture of asphalt and rubber simulates that which is produced in the field.

A mixer has been developed (Ref. 3, 26) for blending asphalt and rubber which also can be used to estimate the mixing time required to achieve the reaction between the liquid asphalt and rubber. The so-called “Torque Fork can be fabricated from component parts available from laboratory supply companies.

Mixing of asphalt and rubber is achieved following the procedures described below:

1. Add asphalt to reaction kettle with stirrer in position.
2. Place kettle in mantle and begin heating.
3. Begin stirring as soon as viscosity of asphalt will allow.
4. Raise temperature slowly to desired level (typically 325° F -375° F)
5. Begin recording viscosity.
6. Complete addition of ground rubber to heated asphalt within 10 seconds from
beginning of rubber addition.

7. After all rubber has been added, begin timing reaction.

8. Continue to mix at 500 rpm until viscosity has become constant.

9. Record time required to achieve constant viscosity.

10. Remove asphalt-rubber blend from mixer.

Preparation of HMA specimens is achieved in a manner similar to that used for conventional HMA. The major differences are the mixing and compaction temperatures which will be slightly higher.

Mixing and compaction procedures described by the Asphalt Institute MS-2 (Ref. 27) for the Marshall mix design procedure should be followed. However, after compaction is completed, the specimens should be allowed to cool to room temperature. After cooling, molds containing specimens should be placed in a 275°F oven to allow the molds to be heated, but not sufficiently long to cause the specimen to be heated. This heating procedure will allow specimen extrusion without risk of damaging the asphalt-rubber HMA. Also, if specimens are removed from the molds at an elevated temperature, rebound of the rubber may cause the specimens to expand preventing an adequate fit in the Marshall stability apparatus.

Laboratory evaluation of the compacted specimens should be conducted similar to conventional HMA measuring bulk specific gravity, maximum theoretical specific gravity, stability, flow, and other physical properties of interest.

**Subtask 1i.**
Identify and justify any changes in specifications and procedures for mix production, laydown and compaction of mixtures using asphalt modified with ground tire rubber.

The following specification and discussion describes special materials and practices required for production of HMA using asphalt-rubber binders. This supplemental specification is intended to be used in conjunction with conventional specifications for HMA construction.

Materials

Asphalt Cement

Asphalt cement shall meet the requirements of FDOT Section 916-1. Acceptable grades for the respective materials will be AC-20 or AC-30 or as specified in the contract. In addition, asphalt shall be fully compatible with the ground tire rubber proposed for the work.

Extender Oil

Extender oil (if used) shall be a resinous, high flash point aromatic hydrocarbon meeting the following physical and chemical requirements:

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, SSU, 100°F (ASTM D88)</td>
<td>2500</td>
</tr>
<tr>
<td>Flash Point, COC, F (ASTM D92)</td>
<td>390</td>
</tr>
<tr>
<td>Molecular Analysis (ASTM D2007)</td>
<td></td>
</tr>
<tr>
<td>Asphaltenes, Wt. %, max.</td>
<td>0.1</td>
</tr>
<tr>
<td>Aromatics, Wt. %, min.</td>
<td>55.0</td>
</tr>
</tbody>
</table>
Ground Tire Rubber

The rubber shall meet the following physical and chemical requirements:

Composition

The rubber shall be dry and free flowing ground vulcanized rubber scrap from automobile or truck tires produced by ambient temperature grinding. It shall be free from fabric, wire, or other contaminating materials except that up to 4% calcium carbonate or talc (by weight of rubber) may be included to prevent sticking and caking of the particles. Moisture content of the rubber shall be low enough so that when blended with the hot asphalt cement and extender oil, foaming of the blend does not occur.

Sieve Analysis (ASTM C136, modified)

Modification of ASTM C136 includes (a) adding 1-2% talc by weight of rubber to prevent the particles from sticking together, and (b) after sieving the surface of rubber particles in each sieve (starting from top sieve) should be rubbed with the hand for one minute to facilitate particles of marginal sizes passing through the sieve openings. The effect of the weight of talc on gradation results is considered negligible.

The ground rubber shall meet the following suggested gradations:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>#8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>#40</td>
<td></td>
<td>85-100</td>
<td>100</td>
</tr>
<tr>
<td>#80</td>
<td></td>
<td>0-20</td>
<td>85-100</td>
</tr>
<tr>
<td>#200</td>
<td></td>
<td>0-5</td>
<td>0-5</td>
</tr>
</tbody>
</table>
Type A gradation is suggested for use in FC-2 mixes and Type B for use in FC-1 and FC-4 mixes. Type B may also be used in FC-2 mixes. Samples of the rubber must be obtained for determination of gradation.

**Chemical (ASTM D297)**

The natural rubber content shall be a minimum of 15% of the total rubber by weight.

**Amount**

The suggested initial amount of reclaimed rubber used in the mix shall be 3-5% by total weight of binder for FC-1 and FC-4 mixes and 10% or less by total weight of binder for FC-2 mixes.

**Antistripping Agent**

Unless it is demonstrated that the asphalt-rubber mixture is resistant to stripping without an antistripping agent, an approved agent shall be specified. If required, the antistripping agent shall be heat stable and approved for use by the Engineer. It shall be incorporated into the asphalt-rubber material at the percentage required by the job-mix formula. Liquid antistripping agents shall be added to the asphalt cement prior to blending with the ground tire rubber. If hydrated lime is used it shall be added in the manner specified for conventional HMA.

**Aggregate**

The use of asphalt-rubber will require little change in the aggregate specifications. The only suggested change is to revise the minimum VMA to 17 for FC-1 and FC-4 mixes.
preparation of Asphalt and Extender Oil

This step can be eliminated if the desired consistency of the asphalt-rubber blend can be achieved without extender oil or most likely if less than 10% rubber is used. If extender oil is necessary, however, the following steps are required: Preheat asphalt cement to between 250°F and 425°F. Blend between 1% and 7% extender oil with the asphalt to reduce the viscosity of the asphalt cement-extender oil blend to within the specified viscosity range. Mixing shall be thorough by recirculation, mechanical stirring, or other appropriate means.

Preparation of Asphalt-Rubber Binder

The asphalt shall be heated to within the range of 350°F to 425°F. Rubber shall be added to the blend in the specified amount. Recirculation shall continue to insure proper mixing and dispersion of all components. Sufficient heat shall be applied to maintain the temperature of the blend between 375°F and 425°F while mixing. After reaching the desired consistency, mixing of asphalt-rubber and mineral aggregates shall proceed immediately such that the longest time between blending and mixing with mineral aggregates is less than 16 hours. Evaluation of the consistency of the asphalt-rubber blend shall occur at intervals not exceeding 4 hours during the storage of the blended asphalt-rubber binder.

Asphalt-Rubber Blend

The blend of asphalt cement, extender oil (if necessary), ground tire rubber, and liquid antistripping agent shall be a uniform, compatible, reacted mixture of components. After blending at 350°F ± 10°F for 1 hour; the blend will be sampled and furnished to FDOT. Test results may indicate that the 1 hour blending time may be reduced. Monitoring the viscosity with a Haake rotational
viscometer during the reaction process will indicate when the blend reaches constant viscosity. Once that occurs, the asphalt-rubber blend is ready for use in construction. Asphalt-rubber may be blended using AC-20 or AC-30 asphalt cement or as specified in the contract.

**Construction**

Prior to use of asphalt-rubber, maximum allowable holdover times (time between completion of blending and mixing with aggregates) due to job delays will be agreed upon between the Contractor and Engineer. However holdovers at elevated temperatures in excess of 16 hours will not be allowed.

A metering device in a drum mix plant shall accurately measure the correct amount of asphalt-rubber for the asphalt-rubber mixes. After mixing asphalt-rubber with the aggregate it can be stored in a surge silo using the same procedure and time requirements as specified for conventional mixes.

The asphalt-rubber mix has greater tendency to “pick-up” when being roiled. Therefore, all tires (wheels) on rollers must be in good condition, water must be properly applied to tires (wheels), and all pads and scrapers must function properly.

Other recommended changes to plant production, laydown and compaction operations are discussed in Subtask 2(i) later to avoid duplication.

**Subtask In.**

*Summarize all changes needed in FDOT and local government specifications and procedures for*
allowing use of rubber in appropriate mixtures.

Detailed discussions of suggested changes to FDOT specifications and procedures appear in various subtasks throughout this report. The following are suggested revisions to various sections of FDOT Specifications that will allow inclusion of rubber in Type FC-1, FC-2 and FC-4 mixtures. These preliminary revisions will need to be updated on a continual basis as experience is gained with these mixtures.

SECTION 320: HOT BITUMINOUS MIXTURES - PLANT, METHODS AND EQUIPMENT

Section 320-2.5 Equipment for Preparation of Bituminous Material

Require an asphalt heating tank capable of maintaining the asphalt-rubber blend at temperatures between 375°F and 425°F and capable of continuously recirculating the blend with a high capacity pump. Also require an asphalt-rubber blending unit (separate or integral part of the heating tank) capable of producing a homogeneous mixture of asphalt and rubber with or without extender oil. See details in Subtask 2c.

Section 320-2.13 Hot Storage or Surge Bins

Permit surge bin only and do not allow overnight storage until further investigations. Refer to Subtask 2i.

Section 320-6.3 Rollers

Do not permit pneumatic rollers because they tend to pick-up the mix. Allow steel wheel roller
only. Refer to Subtask 2i.

**Section 320-6.3.3 Prevention of Adhesion**

Absolutely no diesel fuel or other petroleum distillates shall be used on the wheels of the roller because these materials react with asphalt-rubber and promote adhesion. Use a mixture of lime water, soap solution or silicone emulsion. Refer to Subtask 2i.

**Section 320-6.4 Trucks**

Absolutely no diesel fuel or other petroleum distillates shall be used on truck beds due to aforementioned reasons. Use a mixture of lime water, soap solution or silicone emulsion. Refer to Subtask 2i.

**SECTION 330: HOT BITUMINOUS MIXTURES GENERAL CONSTRUCTION REQUIREMENTS**

**Section 330-4 Preparation of Asphalt Cement**

 Require that the temperature of asphalt-rubber binder not fall below the minimum required for mixing. Refer to Subtask 2i.

**Section 330-6.3 Mixing Temperature**

Mixing temperature range of 325°F to 375°F for dense graded mixtures FC-1 and FC-4, and 275°F to 325°F for open graded mixture FC-2 are recommended for high rubber contents. It is likely
that temperatures lower than recommended temperatures may be adequate because of low rubber content. However, suitability of lower temperatures needs to be verified in the field on several jobs before lowering temperatures. Refer to Subtask 2i.

**Section 330-6.4 Maximum Period of Storage**

Do not permit overnight storage of mix containing asphalt-rubber until further investigations demonstrate that such mixtures have acceptable properties. Refer to Subtask 2i.

**Section 330-10 Compacting Mixture**

Permit steel wheel roller only. Do not permit pneumatic tired rollers. Refer to Subtask 2i.

**SECTION 337: ASPHALTIC CONCRETE FRICTION COURSES**

**Section 337-2 Materials**

Add ‘ground tire rubber’ in Section 337-2.6. The rubber should be dry and free flowing ground vulcanized rubber scrap from automobile or truck tires produced by ambient temperature minding. Do **not** permit the use of cryogenically ground rubber (refer to Subtask 1a). Detailed specifications for ground tire rubber such as composition, gradation and chemical properties are given in Subtask 1j. Two gradations are specified: Gradation A is coarser and is suitable for FC-2 open graded friction course and Gradation B is recommended for dense graded friction courses FC-1 and FC-4 as well as for FC-2. These gradations can be modified based on the availability of rubber and experience in the field. Refer to Subtasks 1a and 1j.
Section 337-3 General Composition of Mixes

Add ground tire rubber to Section 337-3.1. Require 3-5% ground tire rubber by weight of asphalt cement in FC-1 and FC-4 mixtures, and 10% or less in FC-2 mixtures. It is recommended that the FDOT specify different percentages on several jobs to gain more experience in the future. Refer to Subtask 1e.

Section 337-3.3 Grading Requirements

Continue to use the gradations specified for FC-1, FC-2 and FC-4 in Table 331-1 of FDOT Specifications. However, encourage coarser gradations within the respective design ranges given in this table to accommodate thicker asphalt-rubber binder films around the aggregate particles. Refer to Subtask 1f.

Section 337-3.4 Stability for FC-1 and FC-4

Continue to specify minimum stability of 500 pounds. However, revise the flow from 8-16 to 8-18 because mixes containing asphalt-rubber tend to have higher flow values compared to conventional mixes. Refer to Subtask 1f.

Section 337-4 Job Mix Formula

Until the contractors familiarize themselves with the design of mixes containing asphalt-rubber binder, require them to submit a mix design based on asphalt cement as a binder (AC-20 or AC-30). Require the contractor to submit samples of aggregates, asphalt cement and ground tire rubber to be used on each job. The FDOT State Materials Office should then prepare the asphalt-rubber
binder and evaluate the same mix. Refer to Subtask Id on lab method of incorporating rubber into asphalt. This mix should meet the following criteria for FC-1 and FC-4 mixes:

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Marshall Stability, min.</th>
<th>Flow 0.01 in.</th>
<th>VMA, % min.</th>
<th>Air Voids, %</th>
<th>Effective Binder, % min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-1</td>
<td>500</td>
<td>8-18</td>
<td>17</td>
<td>8-14</td>
<td>6.0</td>
</tr>
<tr>
<td>FC-4</td>
<td>500</td>
<td>8-18</td>
<td>17</td>
<td>12-16</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Note that the minimum values of VMA and effective binder content have been increased to allow for thicker asphalt-rubber films.

There is no Marshall design criteria for open graded FC-2 mixes. Refer to Subtask If.

**Section 337.5 Contractor’s Quality Control**

Require the contractor to run the modified extraction test (discussed in Subtask 2g). However, this modified test should be used on a trial basis and refined further if necessary. Require the contractor to supply asphalt-rubber binder on a certification basis supported by records of rubber and asphalt quantities used daily for each project. Samples of those same jobs should have modified extraction tests performed to provide a database for evaluating the modified test. Refer to Subtask 2g.

**Section 337-6 Acceptance of Mix**

Do not accept the mixes based on modified extraction test until adequate experience is gained with this test. Accept the mix based on quantities of ground tire rubber and asphalt used and certified
on a daily basis for a specific project. Refer to Subtask 2g.

**Section 337-7 Special Construction Requirements**

The following mixing temperature ranges are recommended for high rubber contents:

- FC-1 and FC-4: 325°F to 375°F
- FC-2: 275°F to 325°F

It is quite possible that the conventional mixing temperatures are adequate because of the low rubber contents. However, the adequacy of lower temperatures to allow for adequate mixing and handling should be verified on several jobs before the recommended temperature range is lowered. The State Materials Office should set the established temperature for each project. Refer to Subtask 2i.

**CHAPTER 3. FIELD CONSTRUCTION AND CONTROL FACTORS**

**Subtask 2c.**

*Determine or verify the field method of incorporation of the ground tire rubber into the asphalt cement prior to mixing in an asphalt concrete mixture; to include special equipment, if any, temperatures, times, etc.*

The researchers suggest that maintaining the proper proportion of asphalt to scrap rubber can be most effectively accomplished at the time the ingredients are charged into the wet process mixing equipment. The volume of asphalt extender oil blend charged into the wet process mixing tank is measured by a certified asphalt totalizing meter. The volume is converted into a weight \( W_{asp} \)
using a set of conversion tables that relate asphalt specific gravity to temperature. Once the weight of asphalt added to the mixing tank is determined, the amount of rubber \( W_{\text{rubber}} \) to be added can be computed by the following formula:

\[
W_{\text{Rubber}} = (100 \ W_{\text{rubber}} / \% \text{ asphalt in blend}) - W_{\text{asp}}
\]

The asphalt is heated to the desired blending temperature. The calculated weight of rubber is added into the wet process blending unit through a granulated rubber feed system capable of supplying the asphalt feed system and yet not interrupting the continuity of the blending process. Once all the rubber has been blended and fed into the mixing and storage tank, the reaction time begins. Records on each batch should be maintained.

Recirculation is provided to ensure proper mixing and dispersion of all components. Sufficient heat is supplied to the storage tank to maintain the temperature of the blend between 375°F and 425°F (recommended for high rubber contents) for a period between 45 and 60 minutes while reaction occurs. The viscosity of the blend is monitored periodically and recorded. Measurement is made with a suitable rotational viscometer. The viscosity of the blend is maintained between 1000 and 2500 centipoises at the time of mixing with mineral aggregates. After reaching the desired consistency, mixing of the asphalt-rubber and mineral aggregates shall proceed immediately with the longest time between blending and mixing with mineral aggregates less than 16 hours.

Special equipment may be required for the following operations:

1. An asphalt heating tank with a hot oil or retort heating system capable of maintaining the asphalt-rubber blend at temperatures between 375°F and 425°F (recommended for high rubber contents). The tank must be capable of continuously
recirculating the blend of asphalt-rubber and will need a high capacity pump to circulate the
high viscosity asphalt-rubber materials. Pumps developed by Bearcat, Inc. of Wickenburg,
Arizona and currently manufactured and marketed by Crafco and International Surfacing
of Chandler, Arizona have proven adequate for this purpose.

2. An asphalt-rubber blending unit which is capable of producing a homogeneous
mixture of asphalt-extender oil and granulated rubber at the ratio specified in the mixture
design. The blending unit shall have both an asphalt cement feed pump and a pump for the
finished blend of asphalt-rubber. This blending unit maybe separate from or integral with
the asphalt heating tank.

3. An asphalt-rubber supply system equipped with a high capacity pump and metering
device capable of adding the binder to the aggregate at the percentage required by the job
mix formula.

Subtask 2g.

Determining the effect of the ground tire rubber in the extraction test (FM 1- T 164) which is currently
used for Contractor Quality Assurance testing. Identify any changes or modifications which may be
necessary.

In the asphalt extraction test (FM 1- T 164) the asphalt is separated from the mineral aggregate
by dissolving the asphalt in a solvent (trichloroethane). Since the asphalt is 100% soluble in
trichloroethane, all but a very small amount of asphalt trapped in the innermost pores of the
aggregate can be dissolved and the asphalt content determined. When granulated rubber is added
to the asphalt, several things happen that complicate the analysis of extraction test results. First,
the rubber does not dissolve in the asphalt but rather reacts with the asphalt by absorbing oils from
the asphalt and swelling. Therefore, when extracted, most of the solid rubber particles are
separated out with the aggregate and not the asphalt. Secondly, when the asphalt-rubber binder
is immersed in the trichloroethane, a portion of the oil in the scrap rubber is extracted along with
the asphalt in the solvent. Therefore, the quantity of liquid that is dissolved by the solvent includes
part asphalt and part oil from the scrap rubber (see Table 1, for the acetone extractable).

The following modifications to the asphalt extraction test (FM 1- T 164) must be made in order
to determine the percentages of asphalt and scrap rubber in a sample of HMA containing asphalt-
rubber. Two corrections must be made: one for loss of fines through the filter of the Rotorex
centrifuge extractor and the second for rubber oil dissolved by the extraction solvent.

(1) Determine rubber oil dissolved by 1,1,1 trichloroethane. Follow the same procedure
for extracting asphalt from HMA except use samples of laboratory prepared HMA
containing asphalt-rubber. Run the extraction test the same way as if HMA was being
processed. Separate the rubber particles from the aggregate using either of the procedures
noted below. Calculate the loss. This loss is a combination of the loss of rubber oil and the
loss of fine rubber through the filter of the Rotorex extractor. Repeat this procedure a
sufficient number of times to generate an accurate loss figure. Dr. M. Takallou suggests an
average of five extraction test results are sufficient for this calculation.

Since the amount of loss of rubber oils could vary with the rubber product being supplied,
NCAT suggests that this series of tests be performed for each rubber blend used.

(2) Determine the average loss of fines. Dr. M. Takallou suggests that this loss be
determined using samples of HMA prepared using the same job mix formula except that
asphalt and not asphalt-rubber be used as the binder. Five separate extraction tests are suggested to determine the loss of mineral aggregate fines.

The difference between the losses calculated in (1) and (2) represent the combined loss of rubber solid fines and the loss of rubber oils. The first and second portion of this procedure should be conducted on plant produced mixes.

One other caution should be mentioned and that relates to the effect of the accumulated fines on the Rotorex filter. The amount of fines passing through the filter depends on the grading characteristics of the aggregate fines and how clean the falter is. It would be advisable to determine how this loss changes on each project as is done with the vacuum extraction procedure for the retention factor, otherwise, the precision of the test will be affected.

Once the loss of fines due to the Rotorex extraction process and the loss of rubber oil to the trichloroethane are determined, the percent rubber in the mix can be determined. Dr. M. Takallou suggests two alternative methods for separating the rubber particles from the mineral aggregates. Method 1 involves separation by floating the rubber particles out of the mineral aggregate using a solution of sodium bromide (NaBr). Method 2 involves ashing the rubber contained in the aggregate in a muffle furnace at $1112^\circ$F ($600^\circ$C). Dr. M. Takallou suggests ashing the material passing the 4.75 mm sieve for 4 hours at $1112^\circ$F. R.L. Dunning suggests an alternative procedure that begins the ashing procedure by heating over a bunsen burner until the flame goes down and then ashing in a muffle furnace at $2012^\circ$F ($1100^\circ$C) for 30 minutes. Dunning notes that with limestones it would be necessary to recarbonate with $(\text{NH}_4)_2\text{CO}_3$. Dunning indicated that his method can usually be completed within one hour and suggests that the four hours required in the Takallou ashing procedure may be excessive for a production laboratory.
These two methods of determining the rubber content suggested by Dr. M. Takallou are detailed in Appendix B. The FDOT should examine this alternate extraction procedure and determine whether the extraction procedure or the field certification of production of the asphalt-rubber binder provides the most appropriate technique for confirming the quantity of rubber in the binder and the binder content. Initially, NCAT recommends that the FDOT monitor the actual quantities of rubber and asphalt used on a daily basis for each project. After the alternate extraction test is attempted and refined further, if necessary, it should be considered for use.

Subtask 2i.

Determine the effects of asphalt cement modified with ground tire rubber would have on plant production, laydown and compaction operations for mixtures in (e).

Construction of a HMA pavement containing asphalt-rubber as the binder will require certain modifications to current practice. The six elements of the construction process which are affected by use of asphalt-rubber binders are as follows:

- Binder Handling
- Binder-Aggregate Mixing
- Surge Storage
- Transportation
- Placement
- Compaction

In general, as the size and quantity of rubber in the asphalt-rubber blend increases, more dramatic changes need to be made to the construction process. Much of the experience gained to date has
been with asphalt-rubber mixtures containing relatively high rubber contents (16-24% rubber by binder weight) and relatively large particle size (minus #10 mesh) rubber. Therefore, most of the modifications to the construction process are based on experience with this type of material. If lower concentrations (3-5% rubber by binder weight) and smaller sized (minus 24 or 80 mesh) rubber are used, fewer changes in the conventional asphalt concrete production process would be expected.

**Binder Handling**

Asphalt-rubber is produced by the continuous blending of heated asphalt and ground tire rubber in an insulated mixing tank. To achieve desired consistencies, hydrocarbon extender oils may need to be added to the blend depending on the size and quantity of rubber. This might be the case when 10% or more #24 mesh rubber is used in open graded friction course Type FC-2. No extender oil is anticipated if 3-5% #80 mesh rubber is used in Type FC-1 and FC-4 mixtures. Mixing and storage of asphalt-rubber must be accomplished using continuous agitation by means of recirculation and/or mechanical stirring. Added care must be taken while handling asphalt-rubber produced using extender oils or other diluents at elevated temperatures. Precautions usually reserved for cutback asphalts should be followed.

Blending of asphalt-rubber can be accomplished away from the asphalt plant and transported to the site, but provisions must be made for continuous heating of the asphalt-rubber so that temperatures do not fall below 350°F (recommended for high rubber contents). In addition, pump capacities must be high enough to be able to pump the asphalt-rubber at the higher viscosities anticipated. Pumps developed by Bearcat, Inc. of Wickenburg, Arizona and currently manufactured and marketed by Crafco and International Surfacing of Chandler, Arizona have proven sufficient for these purposes.