- make asphalt more viscous
- provide more ductility at low temperatures
- enhance the adhesive characteristics
- increase the elasticity
- enhance the impact resistance at low temperatures, and
- increase flexibility, tenacity and toughness,

Peterson et al (Ref. 34) constructed 16 test sections in Utah and after 24 months of service, made several observations. One of these observations is summarized thus:

“As a consequence of the poor disbursement of rubber in the mix, resulting from adding it at the pugmill, it is likely that many of the beneficial as well as adverse effects of rubber have been distorted.”

In this test, the rubber was added as a latex into the pug mill. It is therefore not a test which included ground tire rubber. One problem that occurred in interpreting the data is that the rubberized binder was more viscous than the neat asphalt, but compaction conditions were essentially the same for all sections. As a result, a lower density (higher voids) occurred in the rubberized sections. As is well known, the strength and performance of a pavement decrease rapidly as voids increase. Thus, the rubberized sections were not directly comparable with the non-rubberized sections.

Levy (Ref. 35) reported that vulcanized rubber is insoluble in asphalt. In the same reference, Rostler (Ref. 36) reports that neoprene rubber is also insoluble in asphalt. He further observed:
“When adding rubber in the form of vulcanized or slightly vulcanized rubber together with sulfur, or when employing insufficient heat and time in adding it to the asphalt, the rubber is primarily present in the asphalt as a network and/or partially swollen particles.”

Dunning (Ref. 37) expressed concern that there may be an uncritical acceptance of the beneficial effect of rubber, that is;

“the rubber has been added to the asphalt. A difference has been noticed and a statement has been made that because this mixture has rubber, it is (by definition) good.”

**Farbenfabriken** (Ref. 38) states the following working hypothesis regarding the use of rubber in asphalt:

1. The rubber firmly binds itself to the maltenes. This prevents the maltenes, which are so important for the general properties of the bitumen, from being lost under the action of traffic and solar radiation, and the residual binder from becoming brittle.

2. The colloidally dissolved rubber confers its properties on the bitumen.

3. A predominantly coarsely dispersed, undissolved or unswelled rubber plays only a subordinate role, since in this state it is unable to confer its typical properties on the bitumen.

4. A rubber which is to be used to modify bitumen must for the major part dissolve or swell strongly in the maltenes. Certain synthetic rubbers, for instance nitrile rubber, is highly
resistant to the actions of solvents or oils because of its chemical composition and would be ineffective in imparting rubber properties to asphalt.

Thompson (Ref. 39), in an extensive study involving various types of rubber particles, concluded that swollen rubbers which remained suspended in asphalt cement were more useful and effective than rubber particles which dissolved.

**Anticipated Problems Using Ground Tire Rubber with Recycling Agents**

**Viscosity.** The ground tire rubber can make the mixture more viscous resulting in a reduction of the penetrating action of the modified recycling agent into the aged binder in the reclaimed asphalt pavement (RAP). Since FDOT primarily uses viscosity graded asphalt cements as recycling agents, increased viscosity will significantly affect the penetrating action. The penetrating action can be affected most if the rubber particles go into solution (which will be the case when 3-5% fine rubber is used) whereas the same action can be enhanced if the rubber particles remain dispersed. To our knowledge no research has been done to quantify the reduction in the penetration capability of a rubber modified recycling agent which is very likely to occur.

**Effect of Rubber Type.** Unknown properties of the rubber particles, particularly chemical, can produce problems. Johnson (Ref. 40) observed that some types of rubbers dissolve while others remain suspended in the bitumen.

Farberfabriken reported that certain synthetic rubbers are highly resistant to the action of solvents or oils due to their chemical composition. Thus there is a need to know the chemical character of the supplied ground tire rubber particles. The dispersibility into a recycling agent may have to be determined experimentally. In recycling hot mixes, research by Kiggundu et al (Ref. 41,42, 43) has
revealed that dispersion is the most important property for production of durable mixes. Durability in a recycled mix can be enhanced by using a modifier with proper dispersing characteristics. These characteristics include a high compatibility ratio (polars/saturates) and a high percentage of aromatics, as determined by a modified ASTM test method D-2007 which is contained in reference 42. The chemical composition of the in situ asphalt in the RAP as well as that of the recycling agent need to be established for the proper selection of these two materials. The work by Kiggundu, in reference 41, with consulting services of Robert L. Dunning, showed that the sensitivity of reclaimed binders can be controlled by recycling agents which contain a sum of asphaltenes and saturates (A+ S) of less than 30. The asphaltenes in the composition are n-pentane asphaltenes.

The composition of the tires which will be used will almost certainly include either natural rubber, SBR or polybutadiene rubber. Although these rubbers do swell very well when placed into asphalt, asphalt crude source can affect the result, and therefore, extensive testing would be needed. This can jeopardize FDOT’S recycling program. Therefore, the use of rubber in the construction and recycling of structural layers is not advisable at the present time. Its use is recommended only in the friction courses which use virgin materials only.

**Obtaining a Uniform Distribution of Ground Tire Rubber.**

**Rubber Blending Procedure.** Another problem arises because there is no standard procedure for blending ground tire rubber into a recycling agent. There are numerous patented procedures, such as the Sahuaro and ARCO process, which include materials, procedures, and equipment. As early as 1954 Rex (Ref. 45) listed two mixing methods which evolved from a laboratory study.

1. Predispersion of rubber in asphalt prior to mixing with aggregates.
2. Adding asphalt or bitumen to aggregate premixed with rubber powder.

He observed that: “Addition of rubber in powder form showed low compatibility within the asphalt-aggregate mix, evident in cores from road test sections where rubber powder had been added in the same manner. However, except for reclaimed mixes, the pre-blended rubbers and the asphalt-plasticized rubber exhibited equal or better compatibility than the control, resulting in improved stability and temperature susceptibility.”

The work by Rex was completed before tire buffings began to be added to asphalt. The powdered rubber to which he referred was one specially developed for his study. Obtaining a uniform distribution of rubber (contained in the recycling agent) in the recycled mix containing RAP is quite uncertain until it is attempted and tested. Therefore, it is recommended that rubber not be used at the present time in the recycling agent when recycling structural layers.

Conclusions

1. Addition of ground tire rubber to recycling agent will increase the viscosity of the binder and, therefore, will reduce its ability to penetrate and effectively rejuvenate the aged asphalt in the RAP. Ground tire rubber should not be used in the construction and recycling of structural layers until its aforementioned effect is investigated and quantified.

2. Obtaining a uniform distribution of rubber (contained in the recycling agent) in the recycled mix needs to be demonstrated. Therefore, rubber should not be used when recycling structural layers.
3. If a small amount of rubber is used in the construction of FC-1, FC-2, and FC-4 friction courses (which are normally 1 inch thick) and no rubber is used in the underlying structural layers, the RAP obtained by milling to 3 inches depth will contain manageable amounts of rubber. This RAP can be recycled with recycling agents containing no rubber.

**Subtask 41**

*Determine the feasibility of using RAP containing an existing mixture with ground tire rubber in a recycled asphalt concrete mixture (re-readability). Determine the procedures for characterizing recovered binder and recommend control tests for quality*

The question of how to recycle old asphalt rubber pavements is one that is often asked, but difficult to answer. John Gray, the president of the National Asphalt Paving Association (NAPA) has expressed concern on this subject as indicated by the following quotation:

“To our knowledge, reclaimed rubber asphalt pavements have not been used in a recycled pavement design. The Industry does not know whether reclaimed rubber asphalt pavements can be used as a recycled material or at what cost. No studies have been made on the environmental impact or consequences of recycling asphalt pavements that contain rubber. There are many questions that must be answered with respect to recycling reclaimed rubber-modified HMA pavement. Will the Industry be able to recycle reclaimed rubber-modified HMA pavement? What effect, if any, will rejuvenating agents have on the hardened rubber? Can rubber-asphalt be brought back to specification, such as penetration and viscosity? How much more difficult will it be to remove the inflexible rubber-modified HMA pavement as opposed to removing unmodified pavements? Do we know enough about milling rubber*
modified HMA pavement? If it cannot be recycled into new pavements, what will happen to the rubber-modified HMA pavement milled from the roadways—Landfill it?" (Ref. 46).

These are legitimate questions, which need to be answered. One hesitates to offer answers based on “expert opinions”.

The purpose of this subtask is to discuss some of the potential problems which may arise when recycling RAP containing tire buffings. This discussion is based primarily on experience, as there is no information in the technical literature on recycling RAP containing rubber.

**Air Pollution Problem**

Air pollution will likely be worse than with neat HMA, if the RAP containing rubber is added at the same place in the recycling process as RAP containing no rubber, both encountering the same heat experience. Although equipment is being developed which should handle the increased air pollution, the initial capital expenditure for such equipment may be 20% higher than that for normal plant equipment, and the operating expense may be higher. The magnitude of the air pollution problem will depend upon the percentage of RAP containing rubber that is used. We anticipate that recycling can proceed with present equipment at a low level of RAP containing rubber without violating air pollution regulations. This is only possible if rubber is used in friction courses and not in structural courses.

**Removal of Old Asphalt Rubber**

The removal of old asphalt rubber pavements with cold planing equipment is an area of considerable concern. The addition of the elastic rubber component to the asphalt should make it
tougher to remove. The asphalt-rubber HMA probably will not shatter like aged asphalt does, but will absorb much more energy before it fractures. Only experience will show whether removal will be a problem.

HMA made with other types of rubberized asphalt have been milled with no difficulty. In the Summer of 1988, a rubberized open graded friction course on the Spokane International Airport was milled with no problems. Since the amount of tire rubber being recommended in this report is relatively small, we do not anticipate a problem.

**Effect of Recycling Agents.** One concern raised by the FDOT is the effect of the recycling agent on the rubber-modified HMA. The following discussion will consider only the effect of the recycling agents on HMA or recycled pavement seals that contain granulated tire rubber. Adding recycling agents will reduce the viscosity of the asphalt (non-rubber) phase of the asphalt rubber, and reduce the volume phase of the swollen rubber particles by dilution. The viscosity of the aged asphalt-rubber in a mix to be recycled depends both on the viscosity of the asphalt phase and, very strongly, on the volume of the particulate when the phase volume is relatively high. Adding a recycling agent to such a material could cause a sharp drop in viscosity in mixes in which the phase volume of the swollen rubber particulate exceeds 50% because of the dilution effect alone. The effect on viscosity would therefore be mainly from the reduction of the viscosity of the asphalt phase. One unknown factor is the effect of the recycling agent and the lower viscosity blend on the swelling of the rubber. Additional swelling of the rubber would counter some of the viscosity reducing effects due to adding the recycling agents.

If the FDOT is concerned about the effect of the recycling agent on the viscosity of a blend this could be evaluated by placing specially prepared buttons of tread stock into hot asphalt and let the buttons swell. This could be done with asphalts of differing viscosities and with differing
amounts of recycling agent. After the rubber has swollen, the 
swell of the rubber is determined, and properties and the composition of the remaining asphalt could be determined. Dunning (Ref. 44) used this technique to measure the rate and extent of swelling of the rubber in various types of asphalt. These specially prepared buttons contained no processing oil so that the effect of such oil would not obscure the results.

According to the preceding discussion a substantial amount of testing needs to be conducted to quantify the effect of recycling agents especially rejuvenation. The use of rubber in structural layers is not recommended until this testing is done.

**Characteristics of a Recycled HMA Containing Asphalt Rubber.**

At the present time nationally, the maximum amount RAP material used in a typical design does not exceed about 40% except in special circumstances, such as overseas air bases. While there are technical reasons for not exceeding that figure, the more practical reason is that often there is not enough RAP available to include more than 40%. The same thing should occur with the HMA modified with asphalt-rubber. Initially there should only be a small percentage to be incorporated into a new mix. Even as the amount of rubber-modified HMA increases, the amount available should not reach that of the RAP.

Since the rubber particles will be distributed into a larger volume of RAP, their effect on viscosity will be greatly reduced because a large part of viscosity effect is due to the packing effect of the swollen particles. From available data, we can safely speculate that mixes containing the recycled rubber modified HMA or seals (such as SAMS and SAMIs) can be designed to perform at least as well as new HMA. The controlling word is “designed”. The gradation of the aggregate in the rubber modified HMA and seals is different from that in regular HMA, therefore, in the mix design
process it will be necessary to establish the proper gradation, keeping the effect of the swollen rubber particles in mind, since they act like elastic aggregates.

We anticipate that before large percentages of rubber modified HMA or seals can be mixed with neat HMA, it will be necessary to develop a mix design system for such materials. In addition to establishing the gradation, the determination of such properties as voids in mineral aggregate, percent voids filled, maximum theoretical specific gravity, etc. may be more difficult. Also, the compaction procedures may be different, although sufficient information should be available for mix design from the original rubber modified mixes. However, the preceding concerns pertain to mixes containing large amounts of rubber. Most of the mix design changes mentioned are not likely to be necessary when small amounts of rubber are used. If rubber is also used in structural layers it can jeopardize FDOT's current successful recycling program because of many unknown mix design factors.

**Dispersibility Problem.** The problem of obtaining a uniform dispersion of the rubber throughout the recycled pavement will have to be solved through material handling procedures. If three inches of pavement were to be recycled, of which one inch (friction course) contained rubber, the very process of milling the pavement should provide significant mixing of the two types of RAP. This rubberized RAP should be kept separate from RAP which contains no rubber. Proper stockpiling techniques should be used so that the horizontal layers can be removed for recycling, vertically.

**Placing old Rubber Modified HMA or Seals in a Landfill**

The question was asked about whether asphalt-rubber RAP material would have to be disposed of in a landfill. If so, what benefit was there of adding the rubber to the HMA initially?
With respect to the last concern, data indicated that there are performance benefits to the modification of HMA with rubber particles, and the use of the SAMS and SAMIs. Therefore, for the life of the rubber modified pavements, those benefits were realized, even if the old rubber modified pavement must be disposed of in a landfill it acts as pavement materials not as tires. Tires work themselves to the surface of a landfill, and if on the surface, collect water, making a breeding ground for mosquitoes while pavement materials do not. In other words, if the tires are put in pavement surfaces they give years of service, and when disposed of, produce no environmental hazard.

The probability that such material would end up in a landfill is quite remote. If not recycled, it could at least be used as stabilizer material based on Florida’s experience in using RAP which was not able to be recycled into HMA.

**Recyclability of RAP Containing Tire Rubber**

Aged RAP mixtures previously built with ground tire rubber may become brittle from age hardening from oxidation. The rate of hardening maybe lower than that of pavements not containing rubber. Schnormeier has discussed studies conducted at Sky Harbor International Airport (Phoenix, Arizona) which show that rubber mixtures appear to age at a much slower rate than those containing only asphalt. Thus the time interval between recycling may be longer for pavements containing rubber. In those studies, the asphalt contained a much higher concentration of rubber than the concentrations of interest in this report, thus whether this level of improvement in durability applies to the low usage level is not known.

The hard and brittle RAP mixture resulting from age hardening may consist of embrittled rubber crumbs which upon extraction may end up as follows:
Additional aggregate
Additional asphaltenes
Additional mineral dust

An attempt to recycle such a mixture may require adding components (aggregate or mineral dust) to correct the gradation as well as a mixture of rubber-modified recycling agent with the following properties:

- Well dispersed rubber particles
- Adequate aromaticity to keep the rubber particles dispersed as well as dispersing the high percentage asphaltenes in the RAP mixture.

Such a hardened RAP mixture may require slightly higher mixing temperatures the second time it is recycled than was required the first time the mixture was recycled. The higher temperatures permit ease of mixing and laydown operations. Suitable mixing temperatures should be determined using the tests discussed earlier under Subtask lb. The aromaticity of the desirable recycling agent may need to be higher than the aromaticity of the agent used the first time the mixture was modified with ground tire rubber.

If rubber is incorporated in friction courses only, its amount in the RAP resulting from 3 inch milling will be minimal and, therefore, the aforementioned mix design and construction factors are not likely to be critical.

Tests and Specifications
Tests may be performed on the extracted binder to judge the level of hardening of the binder. The extraction of the binder needs to be carried out using the experience and methodology suggested by Dr. M. Takallou as discussed in Subtask 2g.

Florida uses only virgin aggregates and asphalt in friction courses to which the rubber will be added. No rubber will be added to the structural mix layers whether the materials are virgin or recycled. Therefore, recycling such a mix would involve only about 1/3 the amount of rubber added to the friction course because of the dilution effect of the milling operation, at least when recycled the first time. Obviously, as time passed, with many times of recycling, the concentration of the rubber would approach 3-5% by weight of the binder (5-10% by volume when swollen).

In running the extraction test on the material to be recycled, the rubber will be filtered out, thus the binder recovered will contain only asphalt, with perhaps a minute amount of processing oil extracted from the rubber. This processing oil is similar to most asphalt recycling agents. A question might arise as to whether the rheology of the extracted asphalt would be materially different than that of the asphalt in the mix which contains the swollen rubber particles. Considering the small amount of rubber present, the viscosity should not be materially increased. However, if desirable, it would be possible to add that rubber back to the asphalt and then measure the theological properties of the binder. The rubber would have to be removed from the aggregate using the procedure suggested by M. Takallou and described in Appendix B.

Running the viscosity on asphalt which contains rubber is a challenge as the rubber may sink to the bottom of the viscosity tube. One way to overcome this problem is to pour the mixture directly into the tube at 275° F and immediately transfer it to the 140° F bath. The viscosity tube should also be larger than that which is used for asphalt, and then run the test at a lower vacuum. The shear
rate should also be calculated and reported, as the mixture of asphalt and rubber may be shear susceptible, even at 140° F.

The mix design should not be different from that used with neat asphalt, as the presence of small amounts of rubber should not significantly alter the test results, especially with a Marshall Design procedure. Suggested values for the Marshall procedure are contained in Chapter 3.

Conclusions

It should be possible to re-recycle asphalt-rubber modified mixtures if small amounts of rubber are used in FC-1, FC-2, and FC-4 mixes only. While there might be some adjustments to the procedures, they should be small. RAP containing ground tire rubber may exist as hard and brittle material due to oxidative aging.

The feasibility of re-recycling may require a more vigorous materials analysis, material selection and probably construction handling. At the levels of the rubber being recommended, however, no significant additional changes are expected.

Test procedures discussed under subtask lb would be sufficient for this material.

CHAPTER 6. OTHER ISSUES INVOLVING RUBBER USAGE

The remaining four issues have been included in this chapter and deal with questions of rubber availability and cost, other disposal methods, and defining short term field projects that can help amplify the inferences from this state-of-the-art study. The four tasks will be addressed separately in the sections below.
Subtask 5h.

Determine the current and projected availability of the type and amount of ground tire rubber for use in asphalt concrete based on the projected use in (e) and the cost to the Department to utilize ground tire rubber in the applicable asphalt concrete mixtures.

Project staff contacted several recycle rubber suppliers and determined that only the Vicksburg, MS plant of U.S. Rubber Reclaiming is currently producing granulated rubber that passes the No. 80 mesh sieve. That material currently costs $30/\text{lb.}$ as compared to $14/\text{lb.}$ for the passing No. 24 mesh rubber. Mr. Gene Morris of International Surfacings, Inc. indicated that work is underway to produce a portable plant capable of grinding scrap tires to pass the No. 80 mesh sieve. Project staff anticipates that as the Florida DOT begins to use this material in surfacing projects and as the demand continues to increase, other recyclers will begin to enter the market. However, to fulfill the goals of Senate Bill 1192, the scrap tire rubber used in Florida pavements should be obtained from the 15 million waste auto and truck tires generated annually in the state of Florida. Therefore, it is desirable that a scrap tire processing unit be located within or close enough to the state to be able to process Florida scrap tires economically. The processing company should be required to certify that only tires discarded in Florida were used to produce ground tire rubber.

It should be pointed out, however, that if 3% of all asphalt binders used in surface mixes in Florida are scrap tire rubber, then only about 10 percent of the 15 million scrap tires could be used in the 3.5 million tons of surfacing placed annually. Increasing the rubber content to the 20% value used in typical asphalt-rubbers would permit the use of almost 70% of the scrap tires produced annually. However, with the very fine surface mixes used in Florida, the NCAT researchers do not recommend increasing the amount of rubber to be used in the FC-1 and FC-4 mixes above 5% or
above 10% for the FC-2 mix. Once successful experience is obtained at the lower rubber levels, the levels can be gradually increased to ensure that the performance of these surfaces is not jeopardized by the addition of more scrap rubber.

In an attempt to determine the cost of adding rubber to the asphalt binder, data from two previously mentioned research studies have been collected and reviewed (Refs. 31 and 47). These data represent the cost to produce a rubber-modified HMA (Ref. 47) and an asphalt-rubber HMA (Ref. 31). Since the rubber modified HMA process (PlusRide) is so different from the wet process in which the rubber is reacted with the asphalt, only the data from reference 31 is appropriate for inclusion in this section. The cost data for production of asphalt-rubber HMA is reported in reference 31 and shown in Table 19. The cost for conventional HMA is $33.58/ton while the cost of the asphalt-rubber ranged from $45.68 to $50.86/ton which represents a cost increase ranging from 36 to 51%.

It should be remembered that these cost data represent mixtures that contain much more granulated rubber than is proposed for use in Florida mixes. Therefore, the cost to produce mixes at this lower rate should decline. In an attempt to determine how the reduced quantity of rubber and reduced reaction time might affect the cost of asphalt rubber HMA, the basic data on which the cost reported in reference 31 were secured and are shown in Table 20. Notice that the blending and reacting cost per ton of binder for the asphalt-rubber is approximately $30. This asphalt-rubber contains 25% rubber which requires a substantially longer reaction and blending time than will the FDOT asphalt-rubber binder using 3 to 5% rubber. In fact the specifications for blending asphalt-rubber with 25% rubber requires a minimum of 45 minutes after all the rubber has been added to the asphalt. Because a substantially lower amount of much finer rubber will be reacted and blended in the FDOT, the reaction rate should be faster for the FDOT material and the total time for both initial mixing of the rubber and asphalt and the reaction should be substantially less,
Table 19. Cost Comparison for Conventional and Asphalt-Rubber HMA Materials in the Continental USA (Ref. 31)

<table>
<thead>
<tr>
<th>Component</th>
<th>Asphalt Cement Binder</th>
<th>Low Asphalt Rubber Content</th>
<th>Medium Asphalt Rubber Content</th>
<th>High Asphalt Rubber Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/Ton</td>
<td>Percent</td>
<td>$/Ton</td>
<td>Percent</td>
</tr>
<tr>
<td>Binder*</td>
<td>8.40</td>
<td>25.0</td>
<td>18.61</td>
<td>40.7</td>
</tr>
<tr>
<td>Aggregate</td>
<td>8.85</td>
<td>26.4</td>
<td>8.85</td>
<td>19.4</td>
</tr>
<tr>
<td>Energy Costs</td>
<td>1.20</td>
<td>3.6</td>
<td>1.28</td>
<td>2.8</td>
</tr>
<tr>
<td>Mixing</td>
<td>3.51</td>
<td>10.5</td>
<td>3.51</td>
<td>7.7</td>
</tr>
<tr>
<td>Haul, Laydown, and Compaction</td>
<td>5.92</td>
<td>17.6</td>
<td>5.92</td>
<td>13.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.66</td>
<td>2.0</td>
<td>0.66</td>
<td>1.4</td>
</tr>
<tr>
<td>Mark-Up (15%)</td>
<td>5.04</td>
<td>15.0</td>
<td>6.85</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>33.58</td>
<td>100.0</td>
<td>45.68</td>
<td>100.00</td>
</tr>
</tbody>
</table>

* 4.8% - asphalt cement binder; 4.2370 - low asphalt-rubber cement binder; 4.73910 - medium asphalt-rubber binder; 5.23% - high asphalt-rubber binder. Asphalt Cement at $175 per ton and Asphalt Rubber Cement at $440 per ton at the plant.
Table 20. Representative Prices (1984) for Asphalt-Rubber Binders per Ton, as Used in Chip Seal and Interlayers (Ref. 31)*

<table>
<thead>
<tr>
<th>A. Materials</th>
<th>cost</th>
<th>%/Ton</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Asphalt Cement</td>
<td>$122.50</td>
<td>28.0</td>
<td>0.14</td>
</tr>
<tr>
<td>$175 per ton f.o.b. refinery</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation -$12 per ton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Rubber</td>
<td>90.00</td>
<td>20.5</td>
<td>0.14</td>
</tr>
<tr>
<td>$0.18 per lb. f.o.b. plant</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation -$12 per ton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Additive</td>
<td>10.00</td>
<td>2.3</td>
<td>0.14</td>
</tr>
<tr>
<td>$0.128 per lb. f.o.b. refinery</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation -$12 per ton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Blending and Reacting</td>
<td>30.22</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>C. Binder Distribution</td>
<td>53.33</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>D. Travel to Job Site</td>
<td>20.00</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>E. Profit, Overhead, Taxes, Insurance, Contingencies, etc.</td>
<td>109.28</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$437.13</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

* Based on industry-supplied data with the asphalt-rubber binder containing 70 percent asphalt cement, 25 percent rubber and 5 percent petroleum additive. Application rate 0.60 gal/yd² or 4.5 lbs/yd².
perhaps by as much as 50%. Therefore we anticipate that the total cost for initial mixing and for blending and reaction should be reduced to the $15 to $20/ton range. This asphalt-rubber blending cost must be converted to a cost per ton of mix in order to determine the probable increase in cost resulting from including rubber in FC-1 and FC-4 as well as FC-2 mixes.

**Estimated cost increase for FC-1 and FC-4 mixes.**

- Typical FC-1 and FC-4 mixes contain 7% binder: therefore, 140 lbs, of binder is required per ton of mix
- For 5% -80 mesh rubber @ $0.30/lb: 7 lbs rubber/ton of mix costs $2.10
- Cost of initial mixing and of blending and reacting asphalt-rubber is assumed to range from $15 to $20/ton of binder

At 7% binder (140 lbs), 1 ton of binder will produce 14 tons of mix

Cost/ton of mix ranges from $1.07 to $1.43

Estimated additional average cost/ton of mix with rubber is $1.25/ton of mix

- Extra Cost for asphalt-rubber:
  - Rubber Cost = $2.10
  - Blending Cost = 1.25

  $3.35/ton of mix

- Current typical cost/ton of HMA in Florida is $31.53
- Increase in cost = ($3.35/$31.53) 100 = 10.6%

**Estimated cost increase for FC-2 mix**

- Typical FC-2 mixes contain 6.8% binder: therefore, 136 lbs, of binder is required per ton of mix
• For 10% -24 mesh rubber @ $0.14/lb: 13.6 lbs/ton of mix costs $1.90
• Cost of initial mixing and of blending and reacting asphalt-rubber @ $1.25/ton
• Extra cost for asphalt-rubber:
  Rubber Cost = $1.90
  Blending Cost = $1.25
  $3.15/ton of mix
• Current typical cost/ton of FC-2 mix in Florida is $50.00
• Increase in cost = ($3.15/$50.00) 100 = 6.3%

Overall the increased cost to produce the asphalt-rubber blend for the FC-1 and FC-4 mixes should be about 10%. Given the probable improvements in fatigue life discussed in Chapter 4, the addition of scrap tire rubber should prove to be very cost effective. Since the amount of rubber and gradation can be increased for the FC-2 open graded mixture, it is advisable for the Florida DOT to consider using the lower cost passing No. 24 mesh rubber in that mix. If the lower cost rubber is used in the FC-2 mix, the percentage increase in cost for that mix is only about 6% even though twice the amount of rubber is used in the FC-2 as compared to the FC-1 and FC-4 mixes.

Subtask 50.

Identify a course of action which could amplify this state-of-the-art study utilizing short term demonstration projects from which conclusions could be obtained in one year after construction time frame.

The FDOT has planned several demonstration projects to evaluate the use of various percentages of ground tire rubber in dense graded friction courses types FC-1 and FC-4, and open graded friction course type FC-2. Construction procedures and in-service performance of these friction
courses containing the rubber modified asphalt binder will be evaluated. Overall economic and ecological aspects of using the ground tire rubber will also be evaluated.

One demonstration project has already been completed in March 1989 on State Route 120 (N.E. 23rd Ave.) in Gainesville using dense graded friction course FC-4. The project consists of the following four sections:

- FC-4 Control section (no rubber)
- FC-4 with 3% minus 80 mesh rubber
- FC-4 with 5% minus 80 mesh rubber
- FC-4 with 10% minus 24 mesh rubber (extender oil used)

The following recommendations are made for future demonstration projects:

1. Attempt 3 to 5% ground tire rubber in dense graded friction courses FC-1 and FC-4, and 10 to 15% in open graded friction course FC-2. These percentages are recommended so that significant statewide changes in mix design, construction practices, and production control will be unlikely.

2. A control section with no rubber must be included in all demonstration projects. The layout of the project should be like a checker board so that each section (control or experimental) is repeated diagonally across in the opposing lane(s). This is necessary because of the potential differences between the opposing lanes such as, traffic intensity (loaded or empty trucks) and highway grades.

3. Past research has indicated that better performance is obtained if the rubber is reacted with the asphalt to form a binder rather than adding it directly as a
powder to the pugmill. However, this conclusion was drawn from performance of mixtures containing large amounts of ground tire rubber (18 to 26 percent by total weight of the blend) of coarser rubber sizes. It is quite possible that small amounts of dry rubber (such as 3 to 5% intended to be used by FDOT) of smaller size (minus 80 mesh) may react with asphalt even if it is added directly to the pugmill. The dwell time in storage silo and/or during transport may provide the necessary time for reaction to occur. Therefore, it is recommended that FDOT include additional experimental sections where direct addition of dry rubber could be attempted and evaluated. If this process gives pavement performance equivalent to that obtained with reacted binder, its adoption will result in substantial economical and logistical benefits.

Most experimental pavement performance studies such as this take 5 to 10 years before firm conclusions on long term durability and performance can be drawn. However, FDOT would like to obtain indications within a year as to whether the use of ground tire rubber in HMA is detrimental or beneficial. The following approach is recommended for possibly achieving that goal.

Normally, long term pavement performance studies also involve periodic core sampling and testing to determine and evaluate the changes in properties such as, percent air voids in the pavement and theological properties (for example, penetration at 77°F, viscosity at 140°F, shear susceptibility, etc.) of the recovered asphalt. Changes in such properties have been known to affect pavement performance with time, and have been found to follow the hyperbolic model suggested by Brown et al (Ref. 48) and confirmed by Lee (Ref. 49), and Kandhal and Wenger (Ref. 50). According to this theory, the changes in these physical properties follow a hyperbolic function with time and approach a definite limit as time increases. Brown et al have suggested the following equation to express the hardening of asphalt in the field:
\[ \frac{A T}{a + bT} \]  \hspace{1cm} (1)

or

\[ \frac{T}{A Y} = a + bT \]  \hspace{1cm} (2)

where: \( AY \) = change in test property (such as viscosity, penetration, shear susceptibility etc.) with time \( T \) or the difference between the zero-life value and the value at any subsequent time;

\( T \) = time;

\( a \) = constant, the intercept of the Eq. 2 line on the ordinate;

\( b \) = slope of the Eq. 2 line; and

\( I/b \) = the ultimate change (limiting value of change) of the property at infinite time.

The terms \( a \) and \( b \) are constants. The quantity ‘\( a \)’ is primarily a measure of the rate of change or degree of *kneeing* of the hyperbolic curve, and the quantity ‘\( b \)’ is the measure of the ultimate magnitude of the variable at infinite time. \( T/AY \) is the reciprocal of the over-all average rate of change of the test property over the life period \( T \). In this form, Eq. 2 is recognized as linear in \( T/AY \) vs. \( T \).

Kandhal and Wenger (Ref. 50) evaluated the long term durability and pavement performance of six asphalt pavements for a period of about 10 years. Experimental data on viscosity, shear susceptibility and percent air voids were fitted to Eq. 2 by the least-squares linear regression methods as shown in Fig. 24. Almost without exception, the fittings, as indicated by correlation coefficients \( r \), were excellent. The values of constants \( a \) and \( b \) and correlation coefficients are given in Table 21. Change in percent air voids has been regarded as positive for plotting, even though percent air voids decrease with age of the pavement.

Since Equations 1 and 2 have but two constants, the mathematical solution depends on determination of \( Y \) at zero life and at any two other values of time. Hence, determination of
Figure 24. T versus T/A Plots (Ref. 50)
Table 21. Linear Regression Data (T versus T/ΔY) (Ref. 50)

<table>
<thead>
<tr>
<th>Test Property</th>
<th>Asphalt Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>1 2 3 4 5 6</td>
</tr>
<tr>
<td>Viscosity at 77 F</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.970</td>
</tr>
<tr>
<td>a</td>
<td>0.495</td>
</tr>
<tr>
<td>b</td>
<td>0.017</td>
</tr>
<tr>
<td>Viscosity at 140 F</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.975</td>
</tr>
<tr>
<td>a</td>
<td>1.531</td>
</tr>
<tr>
<td>b</td>
<td>0.029</td>
</tr>
<tr>
<td>Shear Susceptibility</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.991</td>
</tr>
<tr>
<td>a</td>
<td>27.523</td>
</tr>
<tr>
<td>b</td>
<td>1.740</td>
</tr>
<tr>
<td>Percent Air Voids</td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.982</td>
</tr>
<tr>
<td>a</td>
<td>5.155</td>
</tr>
<tr>
<td>b</td>
<td>0.207</td>
</tr>
</tbody>
</table>
test property values at time zero, or immediately after compaction, with determinations again after
the first and second year of life are sufficient to determine the course of the whole hyperbolic
relationship between test property and time, including the limiting value to be approached near the
end of the performance period. Thus, instead of spreading over a prolonged period a few samplings
and analyses for each year, the same effort may better be expended by increasing the coverage of
sampling in the early life of the pavement. By so doing, the early life values become statistically
more valid, and, from these, the changes to be experienced over later years can be estimated
without waiting out the time (Ref. 48).

Since the FDOT needs indications of performance within one year, it is recommended that the
pavement properties (such as, percent air voids and indirect tensile strength) and recovered asphalt
properties of demonstration projects be determined after 0, 6, and 12 months of service so that the
preceding approach can be used to estimate relative limiting values of changes in such properties
at the end of the pavement life.

Subtask 5p.

Identify and document the feasibility and economics of the use of ground tire rubber in other highway
construction applications.

Introduction

There are several other uses for tires rubber combined with asphalt such as crack fillers. One of
the early uses was as an asphalt-rubber seal coat to prevent crack propagation called a stress
absorbing membrane (SAM). Then, the stress absorbing membrane interlayer (SAMI) was
developed for the same purpose, except that is was sandwiched between two layers of HMA. The
same type of composition has been used very successfully for pond linings and for linings under gold
mine tailings which are leached with a cyanide solution.

**Crack Filler**

It is very difficult to design a reliable crack filling material because the performance requirements
are quite stringent. A crack changes volume as the pavement goes through a thermal cycle,
however, the materials placed in the crack can only change shape. If a crack filler material is very
strong, it may pull the pavement apart, especially asphalt pavements. On the other hand, if it is too
soft and gooey, it may run out of the crack and be sticky and track.

Improved crack fillers have been produced which contain tire rubbers. In fact Shell Chemical has
formulations which contain tire rubbers which, when compounded with the addition of their **Kraton**
rubber, will meet the ASTM specification criteria for joint sealers (ASTM D-3405 and D-3406).
The use of the tire rubber in crack sealants is not a high volume use, but the product has a high
value. It is important, however, when viewing the performance, to realize that whatever crack filling
material is used, it should be expected to fail at some point in time because of the geometry and
change of volume of the crack, and the inability of the crack filler to change volume.

There is a trend away from using tire rubber in crack fillers, although it is believed that the
presence of the particulate adds benefit to the crack filler. One possible cause of the benefit would
be that the particulate act as points at which cracks terminate. This type of action is what provides
the crack propagation resistance to high impact polystyrene.

FDOT has used crack filler material containing asphalt-rubber.
Pavement Seals

There are two distinct uses for asphalt rubber in pavement sealing operations. Following is a description of each.

Stress Absorbing Membrane (SAM)

The SAM consists of a chip seal in which the asphalt-rubber is the bituminous binder. While it is applied with equipment which is used for chip seal application, there are many special details which must be considered before this product is used.

The purpose of using the SAM is to enhance the resistance of the wearing surface to reflective cracking on pavements which have experienced fatigue failure. It is not as effective if placed over pavements which have cracks due to thermal stresses.

One interesting observation on pavements which have been overlaid with the SAM is that traffic appears to inhibit the reflection of the cracks. Cracks which begin to appear will only show up at the edges, there will seldom be evidence of the cracks in areas over which the tires rolls.

The asphalt-rubber material is prepared by placing an asphalt, often a 100/200 grade, in a truck which has been outfitted with a mixer, and 25-30% rubber is added and mixed for a prescribed length of time. The rubber particles are swollen by the asphalt, which causes the mix viscosity to increase. Kerosene is often added to reduce the viscosity to a range where the mix can be sprayed.

The chips are precoated with asphalt and should be heated to obtain the best chance of success. Also, a considerable excess of chips must be used in comparison with a normal chip seal to assure
success. The chip laydown must occur immediately behind the distributor, and the roller must follow immediately behind the chip spreader. Traffic may be allowed on as soon as rolling is completed and the excess chips swept up.

Once the chips get **imbedded** into the asphalt-rubber, the membranes do a good job in holding the chips. It is harder to get the chips imbedded, however, than with a normal chip seal, and if they are not imbedded, they can be lost. The excess chips appear to help achieve good imbeddment.

However, **FDOT’s** experimental project (SR 60- Hillsborough Co) which evaluated this technique did not demonstrate SAM’s superiority over conventional surface treatment without rubber.

**Stress Absorbing Membrane Interlayer (SAMI)**

The SAMI is very similar to the SAM except that an HMA wearing surface is placed over it. Since it will be covered, some relaxation of the precautions discussed above, such as allowing a dirtier coverstone, can be permitted. The purpose of the SAMI is to act as a barrier to crack propagation from cracks in the underlying layers.

Again, **FDOT’s** experimental project (SR 60- Hillsborough Co) which evaluated this technique did not demonstrate SAMI’s superiority over conventional binder surface treatments.

**Pond Linings**

Asphalt-rubber has been used as an impervious pond lining, especially in Nevada where they are used for linings over which gold mining tailings are leached with cyanide solution. The construction process is similar to that used for the SAMI.
This material has also been used for other types of pond lining and for water harvesting. Water harvesting in Arizona involves collecting water in arid areas. A large sloping expanse, such as an acre, of the desert is covered with an impervious coating to collect water. The water so collected from a rain fall is allowed to drain into a pond or watering tank for livestock and wildlife.

**Subtask 5a.**

*Identify and determine feasibility and economics of use of ground tire rubber in non-highway related applications.*

The purpose of this subtask is to describe other potential ways of using tire rubber to provide an economical benefit. Murphy (Ref. 51) covered the research needs for making use of waste tires. In this section, two such potentially high volume and high valued uses currently in progress will be discussed.

**Tires as a Fuel**

One disposal method for old tires is as fuel. A typical tire has approximately 300,000 BTU’s of energy contained in the rubber, oils and carbon black. In addition, many tires contain a couple of pounds of steel. These energy contents per unit volume are very competitive with fossil fuels if ways can be found to economically use that energy. It has been estimated, that the number of tires being discarded each year could produce about 3 million megawatts hours of energy per year. Promising systems for extracting that energy are described below.
A company called Oxford Energy Company, located in Santa Rosa, California collects and disposes of old tires in several ways including incineration. They carry out the whole range of operations for disposing and recycling tires. Oxford Tire Recycling, a subsidiary of Oxford Energy company, collects tires from tire dealers, municipalities, service stations etc. and sorts them for different uses. Some of the tires may be prepared for retreading and reenter the market as tires. Others may be made into various products, such as door mats, etc, shredded into chips for fuel or burned whole for creating energy.

Oxford Energy, Inc. built a $41 million plant in Westley, California to produce 14.4 megawatts of electricity by burning tires. This plant operates like a typical power plant with two large boilers lined with water filled pipes. The tires are burned on a grate at a temperature of 2500° F to produce steam to drive turbines. State-of-the-art technology is used to solve environmental problems which could be associated with the burning of tires. Ammonia is injected to neutralize the nitrous oxides. A fabric baghouse filter collects the particulate, which are rich in zinc and can be recovered, and a lime scrubber removes the sulfur as calcium sulfate (gypsum). The fuel feed inflows tires at a rate of 800 tires per hour.

The steel in tire cords are melted at the temperature of the combustion and shows up as a slag that has been approved as a base material for road beds. This plant can consume about 4.5 million tires per year.

Oxford Energy has plans to construct another plant in Sterling, Connecticut according to an undated article from Tire Review.

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* Oxford Energy Company, 3510 Unical Place, Santa Rosa, CA 95403. 707-575-3939. Robert D. Colman, President.
The economics of electrical production is hard to judge since California law requires that power companies buy power generated by alternate production sources. In 1987, Oxford Energy lost $600,000 on sales of $1.4 million revenue and in 1988 lost $2.15 million on sales of $7.5 million. They are listed on the American Stock Exchange. Whether these losses are related to the basic economics of the process or caused by start up costs which plague any new technology is not known at this time.

By shredding the tires into chips, they may be burned as a fuel for cement plants. As an example, Calaveras Cement Co. in Redding, California burns 60 tons of shredded tires a day which represents 25% of Calaveras' fuel needs according to a recent (but undated) article from the Sacramento Bee Newspaper. Florida Mining and Materials has tested the use of a mixture of shredded tires and coal for its Brooksville, Florida cement plant (Ref. 52).

Energy Products of Idaho is located in Coeur d'Alene, Idaho and has developed a fluidized bed combustion system for burning various types of wastes, including chopped tires. A pilot plant began operation in early 1989 and the licensing process has been completed for construction of a plant in Rialto, California. They believe that the fluidized bed combustion system will outperform plants using grates (Ref. 53). One of the advantages of the fluidized bed is that it is more efficient in cleaning up the out gasses.

Energy Products is owned by JWP, which is listed on the New York Stock Exchange, and has a price earnings ratio of 15. Reportedly JWP is a conglomerate which owns many small energy or environmental related companies.

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Another approach to the disposal of scrap tires is that used in Babbitt, Minnesota, which is near Minneapolis (Ref. 54). This county owned facility (Saint Louis County) is operated by Minneapolis based Rubber Research Elastomers, Inc.” At full capacity, the plant can recycle all parts of three million scrap passenger and truck tires annually. The plant employs 42 full time workers, and expects to add an additional 20 employees by late 1989. The process recycles the whole tire into a variety of products such as roofing, railroad crossties, tire tread, molded mechanical materials, etc. The metal is sold to a scrap dealer. The process has no effluent and uses only electrical energy.

The establishment of the plant was a result of a combination of a technical breakthrough and political action. Fred J. Stark, Jr., (a chemist, and president and chief executive officer) of Rubber Research Elastomers, Inc., developed a method for treating old rubber particles so that they would combine with new rubber in the manufacture of rubber products (Ref. 55). Using this technology, up to 90% recycled tires may be converted into neat polymer based products. The political action was by the Minnesota legislature which limited the disposal of old tires. A company brochure describes the process this way:

“The patented TRICYCLE technology involves the surface treatment of particles of vulcanized rubber with various polymer compounds. Through the treatment of the surface of the particles of ground rubber, the ground rubber is transformed from a dead filler to a live extender or active ingredient. As explained in the U. S. and
foreign patents, by treating particles of ground vulcanized rubber with a small concentration of a polymer compound, unsaturated bonds within the particles of ground rubber can be activated to promote cross linking of chemical bonding with other particles of treated ground rubber or virgin rubber compounds. By applying a secondary treatment, the thermoset (rubber) TRICYCLE compound can be made compatible with thermoplastic (plastic) compounds, thus creating a raw material that is compatible with both thermoplastics and TPR’s.

In mid-1989 the Babbitt, Minnesota plant is operating at about 10% capacity. Management believes, that about 15% capacity is the break even point. Plans include expansion into the Northeast and the Southeast. In the Southeast they believe that the best location is around Atlanta, GA. However, according to Fred J. Stark, Florida could be an attractive alternative.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Based on the review of the literature and the experience of the research team, the following conclusions and recommendations are made. These conclusions and recommendations are very conservative in nature primarily because there is little information in the technical literature that deals with asphalt-rubber HMA prepared with mixes as fine as those used in Florida surface mixes. Additionally, since FDOT is charged to implement the use of asphalt-rubber in HMA construction, the recommendations are structured to ensure that no costly construction blunders result from putting into practice the recommendations of this project. That is, the quality of the surface mixes should not be jeopardized as a result of implementation of the recommendations from this report.

CONCLUSIONS
1. Ambient ground whole scrap automobile, truck, and bus tires can be used with asphalt to produce an acceptable binder for use in FC-1, FC-2, and FC-4 surface mixes in Florida. Cryogenically ground materials should be prohibited as should blends of scrap tire and other waste rubber products. NCAT researchers recommend that the use of scrap rubber be limited to virgin material surface course mixes. Such limited use will avoid having to deal with the issues of re-recyclability of asphalt-rubber HMA which is fraught with technical difficulties that have not yet been addressed by any researchers.

2. Because the Florida surface mixes have such fine aggregate gradations, the FC-1 and FC-4 mixes require rubber grinds that are finer than the normal grinds shown in Table 3.

3. Because asphalt-rubber films surrounding the aggregates will be thicker than for asphalt cement, modifications to some of the Marshall test specification values will be required. Generally for asphalt-rubber HMA’s, the Marshall flow will increase, stability will likely decrease, the VMA will need to be slightly increased, and the binder content will increase. The recommended changes in specifications are included in Table 9.

4. Laboratory prepared asphalt-rubber blends with characteristics similar to those produced in the field can be generated using a suggested procedure included in the report.

5. Based on a review of technical literature, we have concluded that the addition of granulated rubber to HMA should provide increases in fatigue life and reductions in permanent deformation for the asphalt-rubber systems similar to those reported in the literature (PlusRide and asphalt-rubber). Both systems use larger amounts of coarser rubber than that recommended to FDOT. However, we believe that improvements in both areas will occur and will be cost effective even though about a 10% increase in cost of mix
will occur when the asphalt-rubber binders are required. Additional performance benefits should occur with respect to (a) low temperature flexibility, (b) strength retention when wet because of rubber additives, and (c) resistance to oxidative hardening due to presence of rubber antioxidants.

6. Although several problems are anticipated resulting from recycling asphalt-rubber surfaces, the small amount of rubber being proposed for use in FDOT mixes should prevent these problems from being significant.

7. Re-recycling an asphalt-rubber RAP may require a more vigorous materials analysis, material selection process, and care in construction than for recycling RAP containing asphalt as the binder. Problems discussed in the report include the effect of aged rubber on a recycling agents ability to soften the reclaimed asphalt, chemical compatibility between various components in the asphalt-rubber system and the recycling agent, and uniform distribution of recycled rubber in the RAP. No rubber should be used in the structural layers because of these anticipated recycling problems. However, for the near future, no significant problems are expected because of the dilution of the asphalt-rubber RAP (from surface mixes) in the other milled materials (from structural layers).

8. The FDOT should be able to secure sufficient crumb rubber for construction of the early projects from U.S. Rubber Reclaiming of Vicksburg, MS, the only rubber supplier currently producing rubber passing the nominal No. 80 sieve.

9. The additional cost of adding fine crumb rubber to FDOT surface mixes should amount to about 10%. However, we believe that enhanced fatigue and rutting performance will probably offset the additional cost.
10. Using scrap tire rubber in all Florida surface mixes will probably only use 10% of the scrap rubber produced annually in Florida. Therefore other uses for scrap tire rubber should be investigated. Other sources which hold great promise include options for use of scrap tire rubber as a fuel, using technologies similar to those of Oxford Energy Company and Energy Products of Idaho, as well as use as a raw material using technology similar to that of Rubber Research Elastomers.

11. Ground tire rubber has been successfully used in other highway applications such as crack fillers, and stress absorbing membranes (SAM) and interlayers (SAMI) as well as other civil engineering applications such as liners for retention ponds.

RECOMMENDATIONS

1. We recommend that the granulated rubber used in the FC-1 and FC-4 mixes be ground to a nominal size passing the No. 80 sieve with a suggested gradation as shown in subtask 1j.

The rubber gradation for the FC-2 mix can be coarser than that for the other surface mixes and a nominal size passing the No. 24 sieve is suggested.

These recommendations apply to the first construction jobs using these new specifications and should be modified as performance from experimental sections shows that coarser particles can be used. It is desirable to move to coarser particles since the cost of rubber ground to pass the No. 80 sieve is about twice that which nominally passes the No. 24 sieve.
2. The initially recommended percentage of rubber to be used in these surface mixes is:

   FC-1 and FC-4  5% by weight of asphalt  
   FC-2  5-10% by weight of asphalt

3. At this time, it is recommended that the amount of rubber added to the asphalt be monitored during construction and certified in the field. This is suggested primarily because (a) FDOT has not had an opportunity to verify the modification to the extraction procedure included in this report (Appendix B) and (b) no laboratory test method to evaluate asphalt-rubber binders has been developed to the point that it is suitable for specifying the required properties of the asphalt-rubber binder. It is recommended that a Brookfield or Haake rotational viscometer be used in the field to verify that reaction of the asphalt-rubber binder has been completed.

   Test methods such as the modified softening point, force ductility, and Schweyer measurements of shear susceptibility and low temperature viscosity should be investigated by FDOT for use in specifications for asphalt-rubber binders.

4. A summary of the recommended modifications to the FDOT specifications to permit asphalt-rubber to be used in HMA construction are included in subtask in of Chapter 3.

5. The material milled from a roadway constructed with an asphalt-rubber surface should be stockpiled separately from RAP containing only asphalt cement. Proper stockpiling procedures should help ensure that asphalt-rubber RAP of a uniform gradation is fed into the plant cold feed system.
6. NCAT staff recommends that FDOT add to its experimental program: (a) the use of coarser rubber sizes, (b) that the fine gradation, dry crumb rubber be added to HMA as an aggregate to determine if the swell time in storage silos and in transportation is sufficient for the asphalt and rubber to react and produce the superior binder performance obtained with the wet process of producing asphalt-rubber.

7. NCAT recommends that FDOT collect performance data on the experimental projects at 0, 6, and 12 months in an attempt to apply the hyperbolic model discussed in subtask 50, Chapter 6. Previous research has shown that viscosity, shear susceptibility, and percent air voids all follow this model with excellent fit of experimental data to the model.
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**Dr. T. Scott Shuler**

Subtask l(f): Changes in mix design specifications and procedures.
Subtask l(d): Laboratory method of incorporating rubber into asphalt.
Subtask l(j): Changes in specifications for pavement construction.
Subtask 2(c): Field method of incorporating rubber into asphalt.
Subtask 2(i): Effects of rubber on construction operations.

**Dr. Badru M. Kiggundu**

Subtask l(b): Properties of asphalt-rubber for specifications.
Subtask 4(k): Anticipated problems and effectiveness of using rubber with a recycling agent.
Subtask 4(l): Re-recyclability of the RAP containing rubber.

**Dr. Hossein B. Takallou**

Subtask 3(m): Effect of rubber on pavement performance and longevity.

**Dr. Mojtaba B. Takallou**

Subtask 2(g): Changes to the FDOTs extraction test method.

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