NCAT Report 89-03

INVESTIGATION & EVALUATION OF GROUND TIRE RUBBER IN HOT MIX ASPHALT

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DISCLAIMER

The contents of this report reflect the views of the authors who are solely responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views and policies of the National Center for Asphalt Technology of Auburn University. This report does not constitute a standard, specification, or regulation.

PREFACE

This report is the result of a project sponsored by the Florida Department of Transportation (FDOT) and conducted by the staff of the National Center for Asphalt Technology (NCAT) at Auburn University. The NCAT staff was assisted by a group of consultants eminently qualified in the use of crumb rubber in hot mix asphalt (HMA) and construction. The project was initiated directly as a result of the Florida legislature passing Senate Bill 1192 on Solid Waste Management in which the FDOT was instructed to incorporate waste tire rubber into HMA construction.

The bulk of this report is a state-of-the-art review of asphalt hot mix in which the binder is asphalt-rubber or in which rubber has been added as an aggregate. In each section of the report, the existing literature is reviewed and recommendations are then made on how the FDOT could modify test methods or specifications to allow the incorporation of scrap tire rubber while not compromising the quality of their existing surfaces. Where the technical literature did not provide direct information, the staff provided their opinion and recommendations.

The project staff believes that if our suggestions are followed the FDOT can fulfill the directives from the legislature and improve the performance of Florida surface mixes.

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EXECUTIVE SUMMARY

This project was initiated by the Florida Department of Transportation (FDOT) in response to action by the Florida legislature in passing Senate Bill 1192 on Solid Waste Management. In that bill the FDOT was instructed to develop the necessary changes in specifications and procedures, as warranted by research and demonstration project evaluations, to permit the inclusion of granulated tire rubbers in hot mix asphalt (HMA) as a standard practice. The bill also required that an evaluation of current research results and field practice be conducted and that the results be presented to the legislature and the Governor. This report is the result of a review of the current state-of-art plus the opinion of the project staff in areas where inferences were required.

The research team consisted of staff from the National Center for Asphalt Technology (NCAT) at Auburn University and the following consultants who are experts in the use of scrap tire rubber in HMA: Dr. T. Scott Shuler, New Mexico Engineering Research Institute (NMERI), Albuquerque, NM; Dr. Badru M. Kiggundu, CONCORP, Inc., Kampala, Uganda formerly of NCAT and NMERI; Dr. Hossein B. Takallou, CTAK Associates, Portland, OR formerly of Oregon State University; and Dr. Mojtaba B. Takallou, CTAK Associates, and University of Portland, Portland, OR. As can be noted from the references cited in this report, this team has been involved in many of the recent major studies involving the use of scrap tire rubber in HMA in the United States.

This report includes results from the two major processes for incorporating ambient ground, granulated tire rubber in HMA:

(a) The wet process, called asphalt-rubber, in which 18-26% tire rubber is reacted with asphalt at elevated temperatures (375-425°F) for one to two hours to produce a material suitable for use as a binder in HMA construction.

(b) The dry process, called rubber-modified mixes (currently marketed under the tradename PlusRide), in which rubber amounting to about 3 to 5% of the aggregate weight is added to the aggregate before the asphalt is introduced and mixing occurs.

Principal differences between these processes include size of rubber (the dry process rubber is much coarser than wet process rubber), amount of rubber (the dry process uses 2 to 4 times as much as the wet process), function of rubber (in the dry process the rubber acts more like an aggregate but in the wet process it acts more like the binder), and ease of incorporation into the mix (in the dry process no special equipment is required while in the wet process special mixing chambers, reaction and blending tanks, and oversized pumps are required).

Initially this study was directed at a study of all HMA mixes currently used in the State of Florida. However, once the NCAT researchers began to study the issues involved with recycling RAP containing aged asphalt-rubber binders, it became evident that a number of difficult technical issues remain unresolved. In addition, since the FDOT includes RAP material in almost all of its structural layers, it became evident that without answers to these technical issues the NCAT researchers might jeopardize the very successful program for the use of RAP materials in structural layers if they recommended inclusion of rubber in these mixes. Therefore a conservative position was taken and NCAT researchers recommended that scrap rubber be added only to the surface friction course mixes.

Performance results from the literature show that adding tire rubber to HMA construction can increase fatigue life and reduce rutting at least for the standard type of processes. However, because the Florida surface mixes, FC-1 and FC-4 dense graded friction courses and FC-2 open graded friction course, are so fine, neither of the standard processes can be applied. In both cases the standard size rubber particles are too large relative to the size of the largest particles in Florida surface mixes. Therefore, it is immediately obvious that smaller rubber particles must be used. However, the cost of producing these finer ground rubbers will be 2 to 3 times that of current grinds. Since there is no literature dealing with these more finely ground rubbers, the authors have taken a very conservative position relative to the amount of rubber to include in these initial construction projects. We are recommending that the FDOT use 3-5% rubber (by weight of the binder) passing the nominal No. 80 sieve in the FC-1 and FC-4 mixes and that 5 to 10% rubber passing the nominal No. 24 sieve be used in the FC-2 mixes until some field experience is gained, and acceptable performance is demonstrated. Then consideration can be given to increasing the amount of rubber in these surface mixes.

The report contains a detailed list of the modifications required in the Florida standard specifications for the design and construction of these asphalt-rubber HMA using the wet system of incorporating rubber into asphalt. The technology for the wet system is well established, equipment is developed and available, and field performance indicates that the presence of rubber in such mixes produces beneficial effects. Therefore, the authors recommend the use of the wet process rather than the dry process. Laboratory and mechanistic analyses indicate an increase in life can be expected even though the cost of mix will probably increase about 10%.

A series of suggestions have been made for field demonstration projects that will give an indication of the performance for both the conventional and asphalt-rubber sections. A methodology has been suggested to allow performance estimates based on data collected during the first year of life of the demonstration projects. Perhaps this data can assist the FDOT in evaluating the cost-effectiveness of the asphalt-rubber sections.

The incorporation of scrap tire rubber in all friction course mixes in Florida in the quantities suggested would dispose of only about 10% of the 15 million scrap tires produced annually in the state. Other disposal methods are crucial in order to adequately address the total disposal problem. Therefore, several alternative disposal methodologies have been researched and reported in Chapter 6. The most promising methods for disposing of large quantities of scrap tires include their use as a fuel source as well as a raw material in production of other polymeric materials. The most promising processes for use of tires as fuel appear to be those developed by Oxford Energy Company of Santa Rosa, CA and Energy Products of Coeur d'Alene, ID. Rubber Research Elastomers, Inc. of Minneapolis, MN has developed a patented process for treating granulated tire rubber to produce a raw material for use in the production of other rubber products.

Based on this research the authors have concluded that:

(1) Ambient ground, granulated tire rubber can be used in Florida friction course mixes with a minimum effect on the gradations of current surface mixtures and a probable increase the service life. However, the cost will be increased by about 10%.

(2) Current specifications can be modified to account for the addition of small quantities of granulated tire rubber with a minimum of difficulty. Addition of large quantities of rubber would require major changes in the materials used in dense graded friction courses and are not recommended at this time.

(3) A series of carefully designed demonstration projects should be constructed and evaluated before widespread incorporation of rubber in surface mixes. This trial usage will permit the FDOT to refine the suggestions included in this report to more

closely match up with Florida conditions.

(4) The use of scrap tire rubber in the recommended quantities will only use about 10% of the scrap tires produced annually in the state.

(5) The disposal of all the tires produced annually require that a comprehensive waste disposal program be developed that includes use of scrap tires not only in HMA but also in a series of other technologies that use rubber as a fuel and as a raw material for production of other rubber products.

The opinions and recommendations included in this report are those of the authors and do not represent the official position of either the National Center for Asphalt Technology (NCAT), Auburn University, or the Florida Department of Transportation.

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NCAT, August 1989

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CHAPTER 1. INTRODUCTION

BACKGROUND

Of the 200 million waste passenger car tires and 40 million waste truck tires accumulating annually in the United States, 15 million occur in the State of Florida. The use of reclaimed ground tire rubber as an additive in various types of bituminous construction not only solves a waste disposal problem and offers the benefit of resource recovery, it is also of interest to the paving industry because of the additional elasticity imparted to the binder and pavement system. Ground tire rubber is commonly obtained as follows.

<u>Ambient ground rubber</u> is obtained by shredding and grinding (milling) the tire rubber at or above ordinary room temperature. This process produces a sponge-like surface on the granulated rubber crumbs which have considerably greater surface area for a given size particle than do cryogenically ground rubber particles. Increased surface area increases the reaction rate with hot asphalt.

<u>Cryogenically ground rubber</u> is obtained by grinding (milling) the tire rubber at or below the embrittlement temperature of the rubber (liquid nitrogen is usually used for cooling). This process produces clean flat surfaces which, in turn, reduces the reaction rate with hot asphalt. According to the research by the Australian Road Research Board this process produces undesirable particle morphology (structure) and generally gives lower elastic recovery compared to the ambient ground rubber.

A blend of reclaimed ground tire rubber reacted with asphalt cement at elevated temperature has been used as a binder in various types of bituminous construction, rehabilitation and maintenance. This blend is called “asphalt-rubber” and consists of 18 to 26% ground tire rubber by total weight of the blend. This blend is formulated at elevated temperature to promote chemical and physical bonding of the two constituents.

Reclaimed rubber has been used for the following applications:

1. Asphalt-rubber seal coat (ARSC)
2. Asphalt-rubber stress absorbing membrane (SAM)
3. Asphalt-rubber stress absorbing membrane interlayer (SAMI)
4. Asphalt-rubber concrete (ARC)
5. Asphalt concrete rubber filled (ACRF) or rubber-modified asphalt hot mix
6. Asphalt-rubber crack sealer

Only Item 5 (ACRF) uses a simple mixture of asphalt cement, solid ground tire rubber particles (as a partial replacement for aggregate component), and aggregates; the remainder use the “asphalt-rubber” binder preformulated at elevated temperatures.

The Federal Highway Administration (FHWA) has been promoting the experimental use of reclaimed tire rubber for highway applications in recent years through their Demonstration Division. National Seminars on Asphalt-Rubber were held in May 1980 (Scottsdale, Arizona) and October 1981 (San Antonio, Texas).

Acceptance of asphalt-rubber systems has been primarily regional, depending somewhat on the favorable experience gained during experimental stages of use. As a result, information on performance of these systems has been fragmented and difficult to assess. Not only has field data presented interpretation problems, but evaluation of the asphalt rubber material in the laboratory has also been fraught with difficulty.

FLORIDA SENATE BILL

The Florida legislature passed Senate Bill 1192 on Solid Waste Management that requires the Florida Department of Transportation (FDOT) to investigate the use of ground tire rubber in asphalt concrete mixtures. The bill also specifies that the FDOT develop the necessary changes in specifications and procedures as warranted by research and demonstration project evaluation to permit the use of ground tire rubber in hot mix asphalt as a standard practice for asphalt pavement construction contracts.

The Senate Bill also requires that an evaluation of current research results and field practice be conducted and that these results be presented to the Governor and the legislature. The recommendations developed as part of this work are based on either the current state-of-the-art or inferred using the best judgement of the project team. Since the time available to conduct this project was too short to permit laboratory or field evaluations, a set of recommended laboratory and field studies are suggested that will help to verify the recommendations included in this report.

OBJECTIVE AND SCOPE

The purpose of this study is to identify and verify using all available state-of-the-art sources, how ground tire rubber can be utilized in asphalt concrete mixtures for pavement construction meeting standard quality performance related specifications.

Ground tire rubber has been extensively used in surface treatments, interlayers, and joint sealers but the scope of this study is specifically focused on the use of ground tire rubber in hot mix asphalt. Some preliminary work performed by the FDOT prior to this project further narrowed the scope of this study, and resulted in the following guidelines.

- The hot mix asphalt (HMA) utilizing ground tire rubber must meet all relevant performance related specifications (VMA, Voids, Marshall Stability, and Flow). The use of this material should not be recommended where the quality of the mixture is jeopardized, or where alteration of construction practices cannot be achieved with existing technology.
- Both positive and negative aspects of utilizing ground tire rubber in hot mix asphalt should be identified.
- If warranted and justified by this study, changes in specifications and procedures utilized by the FDOT and local units of government should be recommended so that ground tire rubber can be used in applicable hot mix asphalt for standard pavement construction contracts.
- Additionally, this study should recommend a course of action which could lead to the most advantageous short term (1 year) demonstration evaluation of the use of ground tire rubber in hot mix asphalt which would lead to additional recommendations for warranted changes in specifications and procedures.

A list of 17 specific activities that were developed from Senate Bill 1192 were included in the request for proposals (RFP) and form the basis of the work activities included in the following tasks. These 17 items are organized into five (5) areas that form the tasks of the work plan. To facilitate review and evaluation of this report the identification of each subtask item in the list is the same as that used in the RFP.

The following five tasks are addressed in detail in this report with each Task included as a separate chapter:

TASK 1. Specifications and Design Factors

This task has been divided into seven subtasks which cover the following items:

(a) suitable type and size(s) of the ground tire rubber for use in HMA,
(b) properties of rubber modified asphalt cement,
(e) amount of rubber to be incorporated in FC- 1, FC-2 and FC-4 mixes,
(f) changes in mix design procedures,
(d) laboratory method for incorporating rubber into asphalt cement
(j) changes in specifications for pavement construction, and
(n) summary of changes to FDOT specifications.

TASK 2. Field Construction and Control Factors

This task consists of the following three subtasks:

(c) field method of incorporating rubber into asphalt cement,
(g) changes to the FDOT extraction test method, and
(i) effects of using asphalt rubber on construction operations.

TASK 3. Pavement Performance Issues

This task consists of one subtask (m) to determine asphalt on pavement performance and longevity.

TASK 4. Recycling Issues

Two subtasks will address the following issues:

(k) anticipated problems of using rubber with a recycling agent and its effectiveness in rejuvenating the reclaimed asphalt pavement (RAP), and
(1) re-recyclability of RAP containing ground rubber.

TASK 5. Other Issues Involving Rubber Usage

This task consists of four subtasks as follows:

(h) current and projected availability of the ground rubber and its cost to the department,
(o) optimization of short term demonstration projects for faster results,
(p) feasibility and economics of the use of rubber in other highway construction applications, and
(q) feasibility and economics of the use of rubber in non-highway related applications.

In HMA construction in the State of Florida, a wide variety of mix types are used including several types of surface and structural mixes. It is common practice in Florida to use reclaimed asphalt pavement (RAP) materials in almost all structural mixes. This practice results in substantial cost savings, resource recovery benefits, and minimizes a potentially costly solid waste disposal problem. In reviewing the available technical literature, no research studies have dealt with the issues of recycling HMA containing asphalt-rubber binders. Some of the potentially serious difficulties involving recycling RAP containing rubber include: increased air pollution; unknown interaction effects between rubber and recycling agents; questions as to the effectiveness of a rejuvenating agent which has been reacted with rubber in rejuvenating the aged asphalt in the RAP; potential chemical compatibility problems between rejuvenating agents and scrap tire rubber; and intensive testing of unknown types and amounts would likely be required to characterize the aged asphalt-rubber binder in the RAP for use in mixture design.

Since these technical difficulties must be dealt with before the feasibility of recyclability of RAP containing asphalt-rubber binders can be evaluated, the NCAT researchers recommend that separate research be initiated to evaluate this issue. In addition, we recommend that FDOT prohibit the use of scrap rubber in structural mixes until these issues have been resolved. Therefore, the balance of this report concentrates on the use of rubber in FC-1, FC-2, and FC-4 surface mixes.

For additional discussion of the issues of recyclability of HMA containing asphalt-rubber, the reader is referred to Chapter 5 on recycling issues.

The detailed discussion of each task and subtask are contained in the following chapters.

CHAPTER 2. SPECIFICATION AND DESIGN FACTORS

Seven of the items included in the original activity list are considered to be related to specification and design factors. Each of these factors is discussed below using the letter identification included in the RFP. The researchers believe that using the original letter identification will make it easier for the reader to locate the portions of this report that relate to the RFP.

Subtask 1(a)

Determine or verify the type and preprocessing (including sizing) of the ground tire rubber which has the potential to produce acceptable properties in asphalt concrete mixtures used by FDOT.

Since the basic reason for requiring the inclusion of scrap tire rubber in hot mix asphalt (HMA) is to solve a waste disposal problem, this discussion of rubber type and preprocessing will include only tire rubber and not other scrap rubbers. In addition, this study will concentrate on whole carcass rubber rather than tread peel for the same reason. However, tread peel materials can be added to whole carcass rubber for disposal purposes with no detrimental effects since the primary difference between whole tire rubber and tread peel is in the percent of natural rubber with whole tire containing about 20% natural rubber and tread peel containing only about 5%, Table 1 (*1*). Other chemical compositional differences between whole carcass and tread rubbers are of no major significance.

Table 1. Recycle Rubber Products for Asphalt-Rubber Typical Chemical Composition (*1*)

	Typical Chemical Commotion					
	Auto Tires (Whole)	Truck Tires (Whole)	Auto Tread	Truck Tread (Mixed)	Truck Tread (Precured)	Devulcanized (Whole Tire)
Acetone Extractable (%)	19.0	12.0	21.0	16.0	18.5	20
Ash (%)	5.0	5.0	5.0	4.0	4.0	20
Carbon Black (%)	31.0	28.5	32.0	30.0	32.0	20
Total Rubber Hydrocarbon (%)	46.0	54.0	42.0	50.0	45.5	40
Synthetic Rubber (%)	26.0	21.0	37.0	23.0	40.5	22
Natural Rubber (%)	20.0	33.0	5.0	27.0	5.0	18

Rubber Type

In addition to automobile tires, truck and bus tires also pose a disposal problem. However, these tires represent less than 20 percent of the total requiring disposal each year. As can be seen in Table 1 truck tires contain about 8% more rubber hydrocarbons than automobile tires and contain more natural rubber. If truck and auto tires are blended in proportion to their volume an acceptable product should be produced. Figure 1 and Table 2 provide evidence indicating the acceptable properties of asphalt rubber blends containing a larger percentage of natural rubber than whole ground passenger tires. In Figure 1, see sample number 5 as compared to sample numbers 10 and 11 (2). In Figure 1 the elastic recovery of strain is the recovered shear strain 110 seconds after the load has been removed divided by the maximum imposed shear strain expressed as a percentage. The load is applied using a modified sliding plate viscometer at a test temperature of 140°F. Therefore, these data indicate that blends of automobile and truck tires could be used to produce acceptable asphalt-rubber binder for HMA.

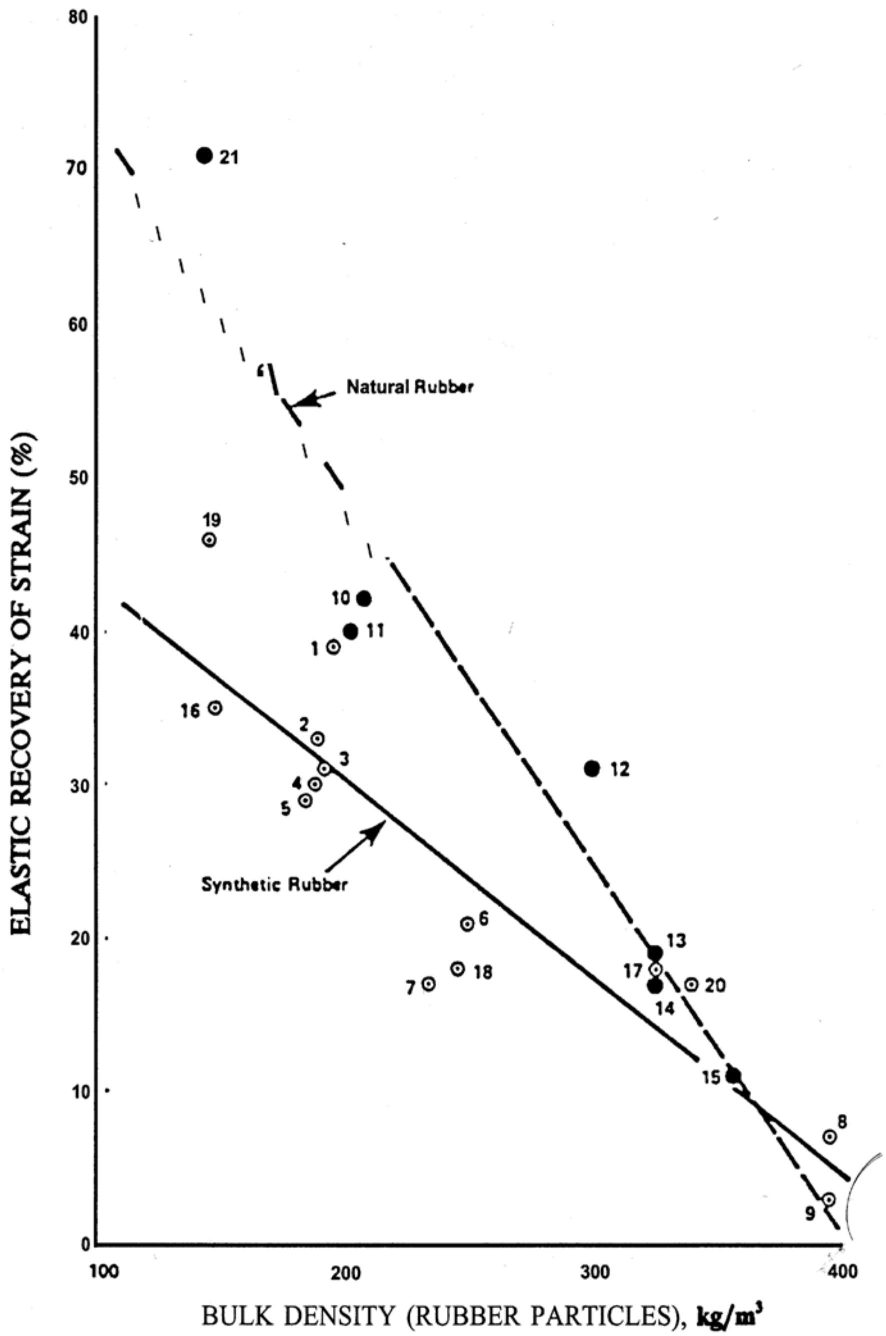

Figure 1. Relationship Between Elastic Recovery and Bulk Density (2)

Table 2. Composition and Method of Preparation of Samples Used in the the Bulk Density Tests (2)

Sample Number	Composition and Preparation Method
	SYNTHETIC
1	100% synthetic blend. Produced by industrial grinding of new passenger vehicle tires during tire rectification.
2	75% SBR*, 25% BR*. Cured tire tread feedstock, laboratory drilled.
3	65% SBR, 35% BR. Cured tire tread feedstock, laboratory drilled.
4	100% SBR. Cured tire tread feedstock, laboratory rasped.
5	30% SBR, 31% BR, 39% NR*. Cured tire sidewalI feedstock, laboratory drilled.
6	Approx. 70% SBR, 25% BR, 5% NR. Mixed buffings from the retreaders plant.
7	100% SBR. Cured tire tread feedstock, laboratory drilled.
8	Mainly synthetic. Tyre retreader’s buffings industrially embrittled in liquid nitrogen and size reduced in a hammer mill.
9	100% SBR. Laboratory crushed after cryogenic embrittlement.
16	100% synthetic blend. Produced by laboratory grinding of used car tire.
17	Mainly synthetic. Undisclosed process.
18	Mainly synthetic. Industrial buffing of tires prior to retreading.
19	100% synthetic blend. Produced by industrial grinding of new tires during tire rectification.
20	As sample 18 with buffings further-treated by a milling process
	NATURAL
10	100% NR. Cured tire feedstock laboratory rasped.
11	100% NR. Cured tire feedstock laboratory drilled.
12	100% NR. Produced by industrial buffing of new truck tires during tire testing.
13	Mainly natural. Undisclosed industrial process involving solvent swelling of the rubbers prior to mechanical size reduction and solvent recovery.
14	100% NR. Laboratory crushed after cryogenic embrittlement.
15	Approx. 80% NR. Prepared by process similar to sample 13.
21	Mainly natural. Prepared by laboratory grinding of a truck tire.

* SBR = Styrene-Butadiene Rubber; BR = Butadiene Rubber; NR = Natural Rubber

Rubber Processing Method

The scrap rubber processing method significantly affects the reaction of the rubber with asphalt and the resultant properties of the asphalt-rubber binder. Oliver (*1*) found rubber morphology (structure) to be the most important factor affecting elastic properties. Oliver included in his study rubber produced by ambient grinding, buffing, rasping, and cryogenic grinding. He concluded that porous surfaced rubber particles, of low bulk density, give asphalt-rubber digestions with desirable high elastic recovery; while angular smooth-faced particles, of high bulk density, give digestions with poor elastic properties (*1*). The angular smooth-faced particles are produced using cryogenic grinding. Shuler (*3*) reached similar conclusions. However, those results were confounded with particle size and natural rubber content differences. Oliver (*1*) further observed that even when very finely ground (25% passing No. 200 sieve), cryogenically prepared particles gave unsatisfactory asphalt rubber digestions. The Australian State Road Authority excludes such specifying a maximum bulk density of 350 kg/m^3 for materials from its asphalt-rubber work by suppliers of rubber particles.

Therefore, the State of Florida should prohibit the use of cryogenically ground rubber products in asphalt-rubber binders for highway pavement use and specify that ambient grinding be required.

Rubber Particle Size

Oliver (*1*) showed that, for tire retreader's buffings, the elastic recovery increases with a decrease in particle size, see Figure 2, with a change of size from a No. 16 sieve to a No. 50 sieve producing more than a 50% increase at 0.5 hours digestion time. Oliver hypothesizes that the improvement in elastic recovery is likely due to the difference in morphology of the particles with the smaller particles being more porous and the larger particles having more flat surfaces. Oliver does not mention the interaction between particle size and reaction time but the data in Figure 2 seem to infer that the rate of swell of the rubber (reaction) for the smaller particle size is much greater than that for the large particles.

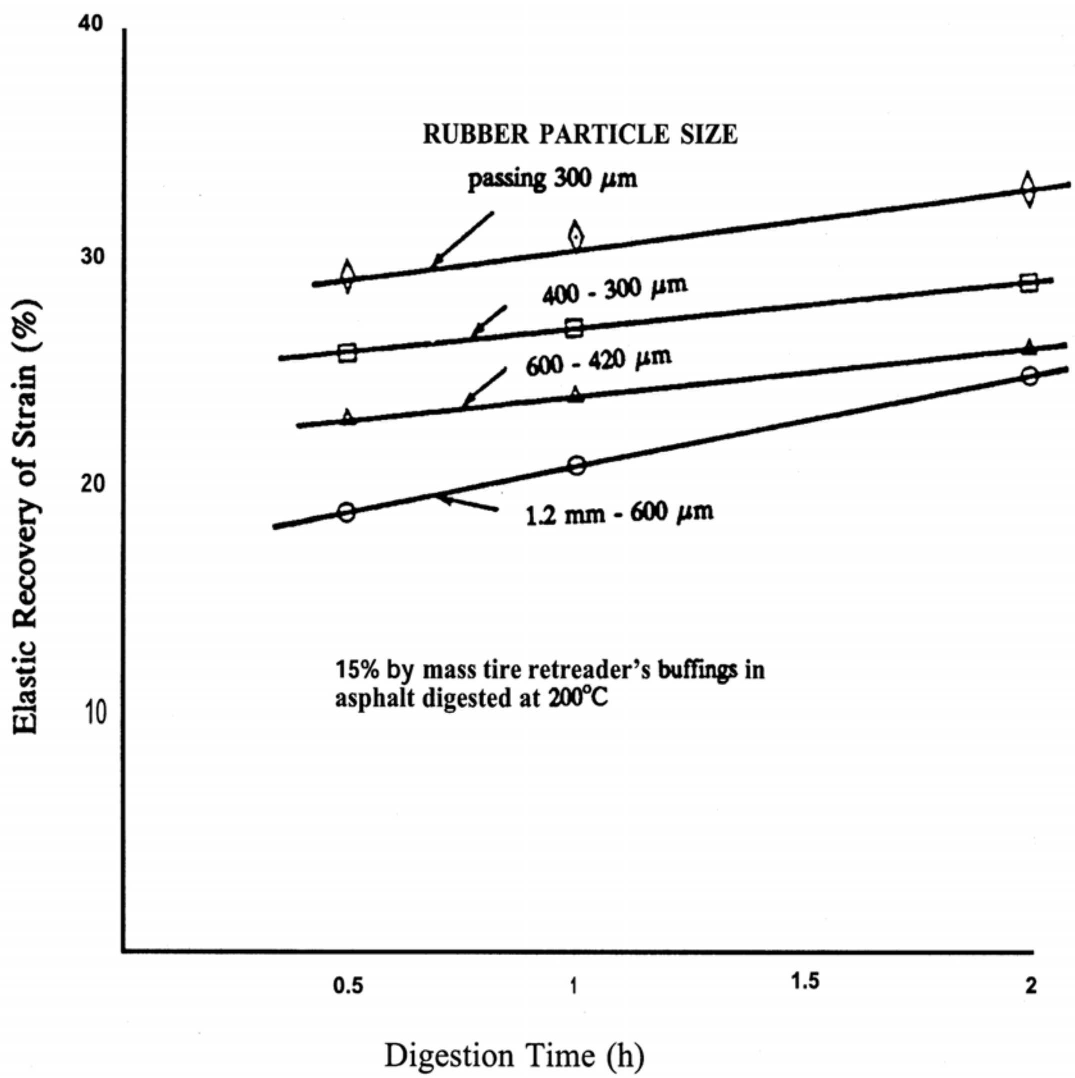

Figure 2. Effect of Particle Size on Elastic Recovery for Tire Retreader's Buffings (*2*)

Shuler (3) reported that the digestion level appropriate for field use of asphalt-rubber binders occurred when the torque level from a rotational viscometer reached a constant level (Figure 3). In fact for the three rubbers investigated by Shuler, Rubber B had the finest gradation with 50% passing the No. 50 sieve and 8 percent passing the No. 100 sieve while Rubber A had only 5% passing the No. 30 sieve. It should be noted that within 45 minutes after the rubber was added to the asphalt both rubbers A and B appeared to have reached a stable viscosity. Rubber A probably reached a constant level that early because it contained a significantly higher percentage of natural rubber (18.39%) than did Rubber B (11.2%). Notice that Rubber C which contained no natural rubber took about 90 minutes to reach a constant level.

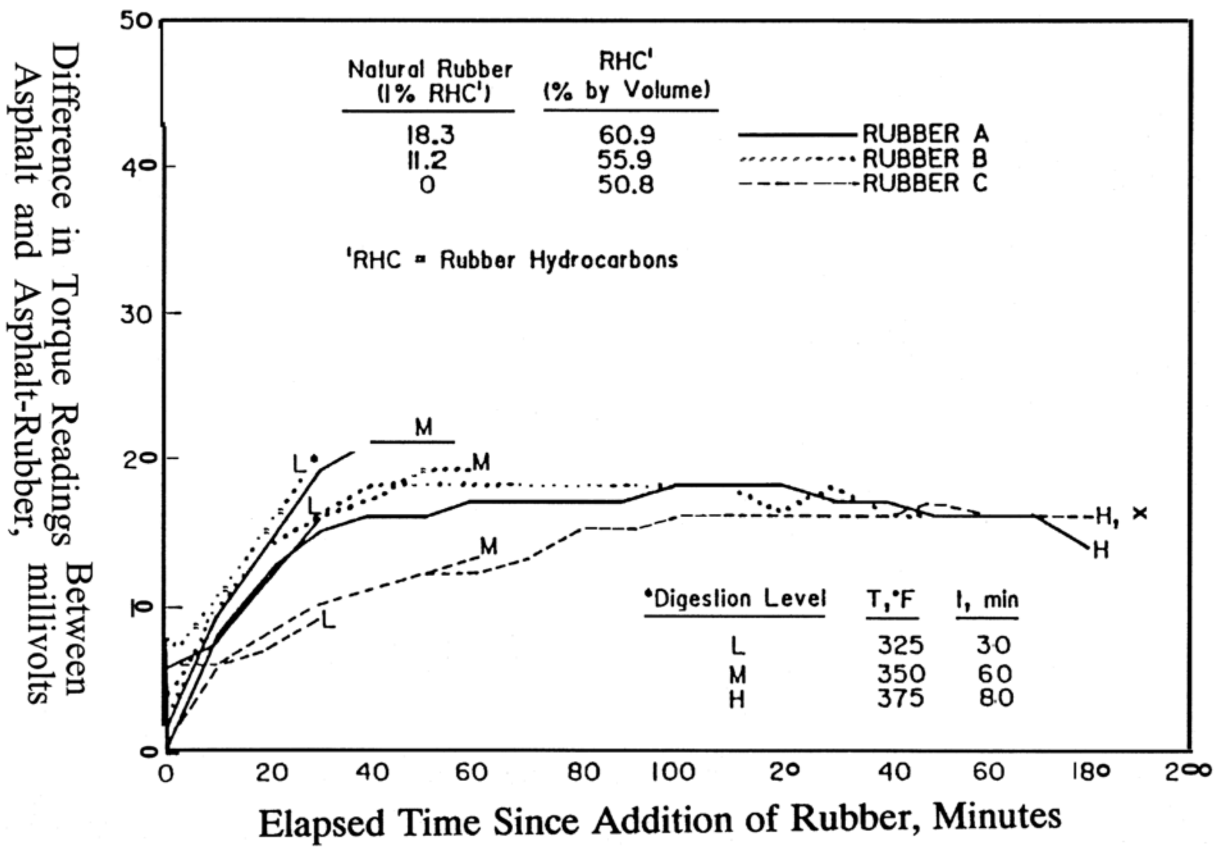

Figure 3. Torque Fork Output for Three Rubbers Used in El Paso at 22 Percent Rubber and Three Digestion Levels (3)

One must conclude then that reducing the size of the rubber particles included in an asphalt-rubber binder should decrease the reaction time as indicated by the time required for viscosity to reach a constant level. One other factor must be considered relative to particle size and that relates to the incorporation of solid rubber particles into the gradation of the Florida FC- 1 and FC-4 dense graded friction courses. The specified gradation range for the FC-1 and FC-4 mixes (4) as well as the typical size distribution for recycled rubber products normally used in asphalt-rubber (1) are shown in Table 3.

As can be seen in Table 3 the FC-1 and FC-4 mixes have a very fine particle size distribution with a majority of the material smaller than the No. 10 sieve. Generally these mixes are a blend of crushed screenings and fine concrete sands that have a large percentage of materials in the No. 10 to No. 50 sieve range. This is the same particle size range as most of the commercial recycled rubber products. Therefore it would be desirable for the recycled rubber particles to be finer than this range so as to fill up some of the gaps in the typical gradation for the FC- 1 and FC-4 mixes. In addition, the smaller rubber particle size would react faster with the asphalt thereby reducing the time the asphalt-rubber is in the mixing unit and increase the production of each unit. However, reducing the size of the recycled rubber particles will increase the rubber processing cost.

Table 3. Size Distribution for Florida FC-1, FC-2, and FC-4 Mixes (*4*) and for Typical Recycled Rubber Produced for Asphalt-Rubber (*1*)

Sieve Size	Florida Mixes			Recycled Rubber Type					
	FC-1	FC-2	FC-4	I	II	III	IV	V	VI
1/2 in.	100	100	100	---		---	---	---	---
3/8 in.	---	85-100	---	---	---	---	---	---	
No. 4	---	10-40		---	---	---	---	---	---
No. 8	---	---	---	100	---	---	---	---	100
No. 10	55-85	4-12	75-90	95-100	---	---	100	---	---
No. 16	---	---	---	---	100	100	95-100	100	
No. 20	---	---	---	---	---	---	50-80	85-100	35-100
No. 30	---	---	---	0-10	60-90	95-100	25-55	40-80	30-55
No. 50	---	---	---	0-5	0-20	30-60		---	
No. 80	---	---	---	---	0-5	15-35	---	---	---
No. 100	---	---	---	---	---	---			4-20
No. 200	2-8	2-5	2-6	---	---	0-10		---	---

For the FC-2 open graded friction course, any of the rubber products in Table 3 could be used so far as the gradation is concerned. However, use of fine rubber particles in the FC-2 mixture could significantly decrease the drain down of asphalt off the aggregate particles prior to placement thereby allowing the binder content to be increased. An increase in binder content should reduce asphalt aging and improve durability of this very important mix. One current construction difficulty that may be helped by the use of small rubber particles is related to restrictions on placement temperature for FC-2 mixes. If the air temperature is below 60°F, current Florida specifications prohibit placing of FC-2 mixes. Since the incorporation of fine rubber in the asphalt should decrease the drain down at any temperature, the FC-2 mixes maybe heated to higher temperatures without drain down. This may allow the minimum paving temperature for FC-2 mixes to be lowered in the future.

Therefore, it is the recommendation of the project staff that finer rubber particles than those included in Table 3 be specified by the FDOT for use in FC- 1 and FC-4 and that rubber similar to type III is acceptable for use in FC-2 mixes. Results to date with construction of experimental sections in Florida indicate that the recycled rubber particles passing the No. 80 sieve have worked well. Therefore, we recommend the continued use of these finer gradations of ambient ground, recycled rubber in Florida mixes.

Subtask 1(b)

Identify properties of asphalt cement modified with ground tire rubber which could be used as specification requirements.

The identification of properties of asphalt cement modified with ground tire rubber which could be used as specification requirements is an ominous task because the combined asphalt-rubber material is complex and lacks homogeneity. However, review of literature reveals that a number of conventional tests used to characterize asphalts, namely viscosity, penetration, ductility, softening point, and others have been used by various investigators to test the complex asphalt-rubber binder system. Credence shall also be drawn from tests defined and used with polymerized asphalt materials. Unfortunately, few reported attempts show that asphalt cement tests can be successfully used to evaluate asphalt-rubber blends. Repeatability of many of the asphalt cement tests depends on uniform consistency of the asphalt. Because asphalt-rubber is a blend of asphalt and fine rubber particles, the discrete nature of the rubber particles produces considerable variation in test results. Table 4 lists most of the tests which have been applied to evaluate asphalt-rubber materials.

Table 4. Laboratory Tests Used to Characterize Asphalt-Rubber

Laboratory Procedure	Reference Number											
	2	5	6	7	8	9	10	11	12	13	14	15
Ring & Ball Softening Point (R&B Test)	X	X										
Modified R&B Softening Point (Phase-Change Temperature)					X	X	X	X				
Absolute Viscosity at 140°F	X											
Ductility at 39.2°F and 77°F	X						X					
Force Ductility	X		X	X	X	X	X					
Constant Stress (Schweyer)	X		X	X	X	X		X				
Toughness/Tenacity		X					X		X	X		
Sliding Plate Microviscometer Rheometer										X	X	
Falling Coaxial Cylinder Viscometer							X					

<u>Discussion of the Laboratory Tests</u>

Tests which are used frequently are discussed here. The frequently used tests are selected from the list in Table 4 determined by the number of times each test is cited in the references. Their repeated use in the published research suggests that the following tests hold promise for future development of specifications:

- Viscosity (not listed in Table 4)
- Modified and standard softening point
- Force ductility

- Viscosity at constant shear stress (Schweyer)
- Toughness/tenacity, and
- Gradation or sieve analysis (not listed in Table 4)

Viscosity

The Brookfield viscometer has been used to determine the viscosity of asphalt-rubber blends at 140°F and 350°F. Typical specified ranges for blends containing 15-26% of # 10-#50 rubber by weight of binder are as follows:

Viscosity at 140°F (Brookfield)	7,000-60,000 poises
Viscosity at 350°F (Brookfield)	1,500-4,000 centipoises

Since only 3-5% rubber is intended to be used by FDOT, the viscosity of the blend can be determined by the Brookfield viscometer. However, the specified ranges will have to be determined experimentally by blending rubber and asphalt cement (AC-20 or AC-30) from various sources.

The Haake Rheometer which is a rotational viscometer can also be used to monitor asphalt-rubber blends. This viscometer (latest model) can test these blends at temperatures from ambient to 250°F with a viscosity range from 10° to 10^{10} poises at shear rates from 10^{-3} to 10^{2} s^{-1} and can test both Newtonian and non-Newtonian fluids.

Modified Softening Point Test

This test, a modification of ASTM D36, was developed at the New Mexico Engineering Research Institute. Shuler (*6*) termed the modified version "Phase Change Test." Newcomb et al. (*7*, *8*, *9*) observed that phase change temperature was characteristic of the rubber particles. Phase change temperatures were further noted to increase with the storage of the asphalt-rubber mixture. In Reference *9* a correlation with an R value of 0.9 was established between compliance and the value of modified softening point for the asphalt-rubber mixtures evaluated. Therefore, the value of the softening point could potentially be used to estimate asphalt-rubber compliance. This test is simple and the equipment is relatively inexpensive. The modified test is reported (*9*) to give relatively lower softening point values than the standard ring and ball test.

Since only 3-5% rubber is intended to be used in the binder by FDOT, it is quite possible that the standard ASTM softening point test (D36) can serve the purpose. However, minimum softening point values to be specified must be determined by blending rubber and asphalt from various sources. Typically, a minimum softening point of 130°F is specified for an asphalt-rubber blend containing AC-20 asphalt and 15-26% rubber (# 10-#50).

Force Ductility Test

This test was developed in the Utah Department of Highways for evaluation of tensile properties of asphalt cement by Anderson et al. (*16*). Its use with asphalt cement was somehow limited because these binders do not possess high tensile strength and thus the test has found more meaningful use for polymerized and asphalt-rubber materials.

In the force ductility test, load cells are used to monitor the force necessary to break samples of constant cross-sectional areas. The load and displacement data obtained from this test are used to calculate compliance and the work needed to fracture the sample.

The results from this test are typically of the form shown in Figure 4. Button et al. (*12*) report that the stiffness due to the asphalt alone and that due to the rubber and/or polymer can be differentiated. In Figure 4b the slope of the left part of the first hump is characteristic of the asphalt while the corresponding slope of second hump is due to the rubber/polymer. Button et al. (<u>*12*</u>) further proposed that the occurrence of a double humped curve suggests compatibility between the rubber/polymer and the base asphalt. Thus absence of compatibility of the rubber/polymer with the asphalt can be indicated by lack of a second hump as indicated in Figure 4d. The term "compatibility" is assumed to imply that the rubber/polymer is very well dispersed in the asphalt. King et al (<u>*13*</u>) on the other hand report that the slope of the second hump represents rubber-polymer modulus and is always related to the polymer tensile strength. The double hump is not always an indicator of compatibility since some additives result in a homogeneous material with only one hump.

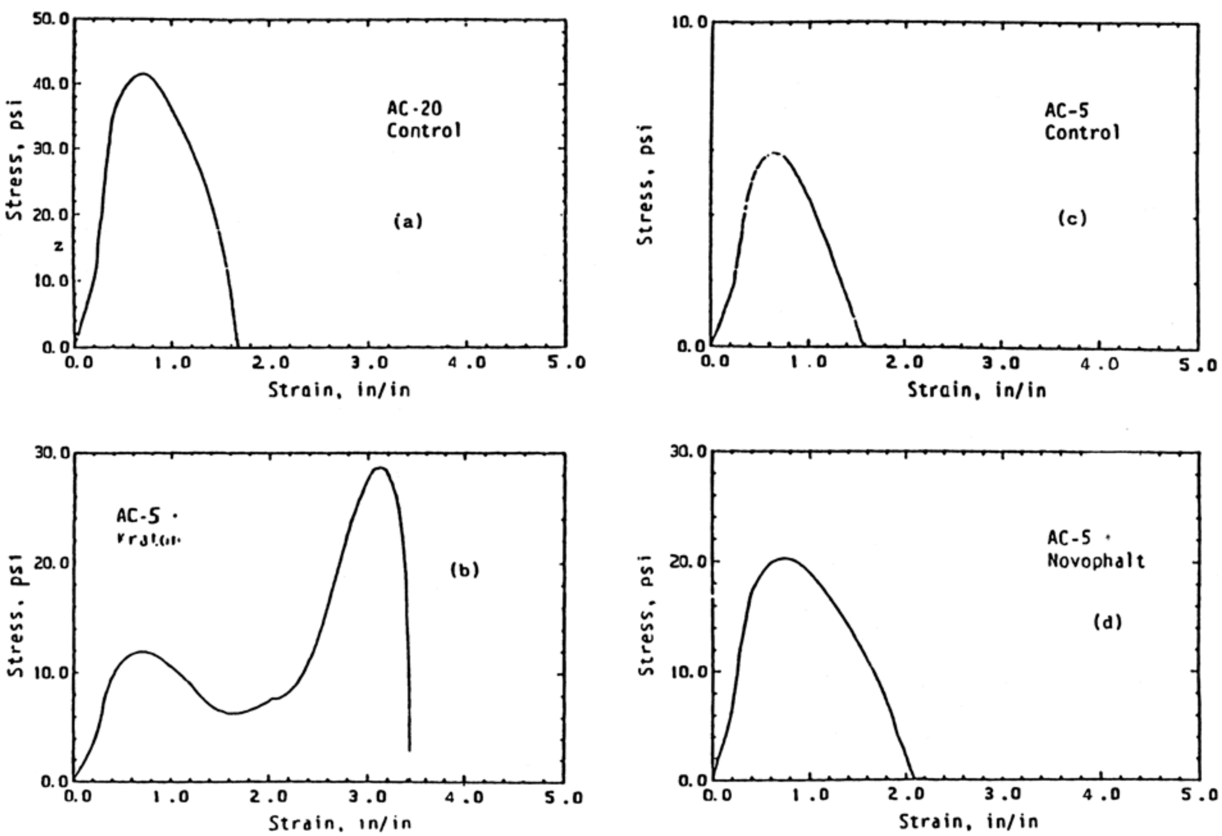

Figure 4. Typical Stress-Strain Curves From Force Ductility Tests at 30.2°F cm/min for Unmodified and Modified Texas Coastal Asphalts

This test is simple to run, the apparatus is a modification of ASTM D113 test and a recent study by Shuler (<u>*3*</u>) presented improved precision and practicality of the test. This test is currently under consideration for standardization by an ASTM D04 sub-committee.

<u>Viscosity at Constant Shear Stress (Schweyer) Test</u>

The viscosity at constant shear stress test was developed by Herbert Schweyer et al (<u>*17*</u>) to test asphalt cements. Jimenez (<u>*11*</u>) extended the use of the viscosity at constant shear stress test to asphalt-rubber modified materials. Jimenez made a number of modifications to the test in order to minimize the possible influence of the size of rubber particles on the measured viscosity values. These modifications are contained in References <u>*9*</u> and <u>*11*</u>.

The results from the viscosity at constant shear stress test can be used to establish the following:

- A unique relationship between shear stress and shear rate leading to a maximum stress.
- The theological character of the material tested as indicated by a shear susceptibility parameter.
- The viscosity values which can be measured at low and variable temperatures and,
- The viscosity at a constant power of 100 watts/m 3 can be used to compare various materials.

Newcomb et al (9) showed that for the three rubber systems included in the study, viscosity at constant power of 100 watts/m^3 achieved a peak value at 375°F. This result suggests that blending the various rubber types used in Newcomb's study at higher temperatures would degrade the mixture and possibly render it tender. Yet at a lower temperatures the mixture studied would be too stiff and hence difficult to handle during construction operations. Thus, this test has potential in the selection of temperature guidelines for mixing and laydown operations during construction.

Newcomb (8) used the viscosity at constant shear stress and modified softening point (S.P.) data to establish a linear regression with a correlation coefficient of 0.83. Thus, for the types of materials studied in Newcomb's work, the viscosity values at constant power of 100 watts/m^3 can be reliably estimated from modified softening point data.

Toughness/Tenacity Test

These two properties are characteristic of a material's tensile strength. They are determined basically using Benson's Toughness and Tenacity Test (*18*). A metallic hemispherical head is embedded in hot molten asphalt or asphalt-rubber/polymer to a depth of 7/16 in. The head and the medium are cooled to 77°F. The head is then pulled from the media at the rate of 20 inches per minute and a load deformation curve is plotted as shown in Figure 5 (5). Toughness is defined as the work represented by the total area under the curve, and tenacity by the area bounded by the curve at high elongation and a projection of the curve directly from peak to the axis as shown in Figure 5.

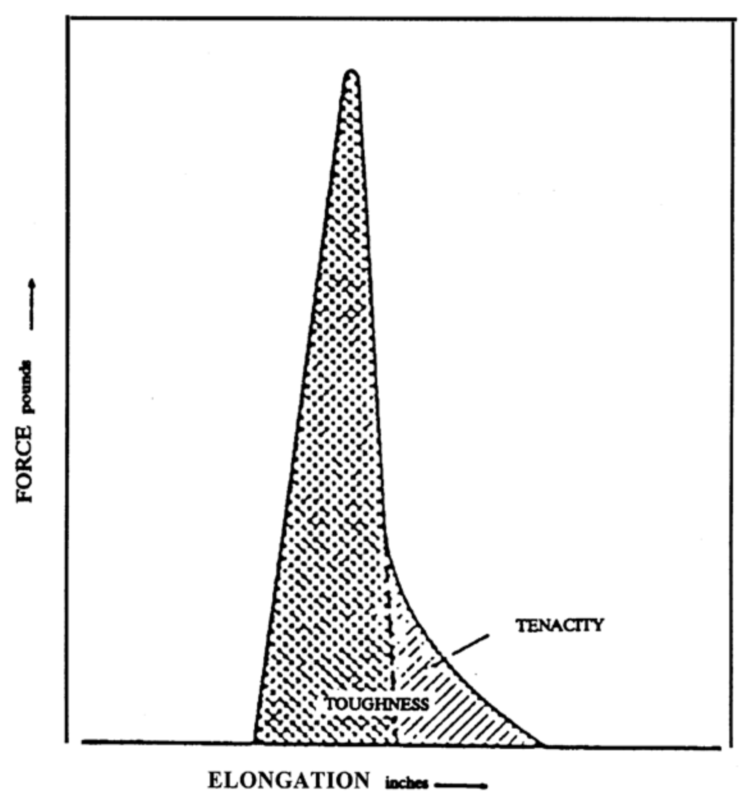

Figure 5. Force-Elongation Curve (5)

Collins (*10*) reports that the physical properties which relate to the performance of an asphalt system are low temperature ductility and tensile properties reflected by toughness and tenacity. Collins stresses that ductility, toughness, and tenacity should be considered together because they contribute to improved aggregate retention and improved low temperature susceptibility. King et al (*13*) on the other hand, reported that although the toughness-tenacity is currently used by the Federal Aviation Administration and the states of Colorado and Utah to specify polymer-modified AC-20R, the test does have some drawbacks. These drawbacks include: 1) the test is normally run at ambient temperature at which small changes in temperature can significantly affect the viscosity and hence toughness/tenacity results, 2) the sample cross-sectional areas are not uniform thus test repeatability proves difficult, likewise data reproducibility can be difficult to achieve, and 3) lastly, the subjectivity involved in dividing the curve between toughness and tenacity regions poses a significant difficulty.

However, the test does appear to be simple to run and the equipment seems to be relatively inexpensive.

Gradation Or Sieve Analysis

Ground rubber used in asphalt mixtures must meet specified particle sizes. The sizes can vary from the No. 16 to No. 25 sieves or from the No. 10 to No. 30 sieves as reported by Decker (*19*). However, before these sizes are determined, whole gradations are usually conducted as given in Table 5. The process of manufacture of the ground rubber and the portion of the tire can affect the gradation results as illustrated in the tabulated results. Sieve analysis of ground tire rubber is run in accordance with modified ASTM C136. The modification consists of 1) adding 1-290 talc by weight of rubber so that particles do not stick together, and 2) after the sieving is completed the surface of rubber particles on each sieve are rubbed with the hand for one minute so that particles of marginal sizes can pass through sieve openings of each sieve beginning at the largest sieve. The effect of the weight of talc on gradation results is considered negligible.

Table 5. Gradation of Rubber Particles for Rubber-Types in the Study (*9*)

Sieve Size	TPo .44 Percent Passing	C-104 Percent Passing	APC-10 Percent Passing
No. 4	100	100	100
No. 8	100	100	100
No. 10	100	99	100
No. 16	87	52	59
No. 20	32	29	31
No. 30	2	14	13
No. 40	1	8	7
No. 50	0	4	3
No. 100	0	1	1
No. 200	0	0	0

TPO.44 = ambiently ground automobile tire treads.
C-104 = ambiently ground whole automobile tire carcass.
APC-10 = Cryogenically produced whole tire carcass.

Other Tests

Listed below are tests which are increasing in popularity in current research efforts. King et al. (13) lists the following:

Dropping ball
Creep Response-Elastic Recovery
(a) Elastic Recovery by Ductilometer
(b) Torsional Recovery Test
(c) ARRB Elastic Recovery Rheometer
(d) Dekker Elastic Recovery Device

Each of these tests is briefly discussed below.

Dropping Ball Test

This is a very simple and inexpensive test procedure which can be used to determine the tensile strength of a polymerized material. It was developed in the Elf Aquitaine research laboratories in France and subjects the test specimen to constant stress conditions. An 8.0 g asphalt sample is poured into a machined metal cup and a ball of specified dimensions is embedded to a preset depth. The apparatus is inverted so that the ball is free to fall. The time required for the embedded portion of the ball to reach the point tangent to the surface of the cup is defined as t1.

The time required for the ball to drop from that tangent plane to a point 30.0 cm below is defined as t2. The time t1 depends somewhat on the viscosity of the asphalt or its initial tensile strength. The time t2 also depends somewhat on viscosity but it is primarily affected by the tensile strength of the asphalt as it is stretched. The ratio t2/t1 provides an approximate relationship between the elasticity or tensile strength after elongation and the original viscosity.

King et al. (13) reports that this test has the same disadvantage as the toughness/tenacity test. However, the dropping ball test does seem to offer potential for use in field applications. This test ‘is still under development.

Creep Response-Elastic Recovery

The ability of a polymer or rubber-modified asphalt to recover elastically is a most desired performance requirement. Since creep elastic recovery per unit time or specify is time dependent, it is necessary to either monitor the time interval at which recovery is to be determined. Four methods or procedures for monitoring elastic recovery are discussed below:

(a) Elastic Recovery by Ductilometer-A standard ductilometer specimen is stretched to 20 cm at 50°F and held for 5 minutes. The specimen is then cut in the middle with a pair of scissors and allowed to stand undisturbed. The combined length of the two halves is determined after one hour and percent recovery is determined as follows:

$$\% \text{ recovery} = ((20 - X)/20) \quad 100$$

where X = length after one hour.

This test is reported to be simple, uses readily available equipment with good temperature control, and has good reproducibility. Thus, this test is considered to be a good candidate for use in polymer or rubber-modified asphalt specifications.

(b) Torsional Recovery Test-Snyder et al (<u>*5*</u>) 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 degrees 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. (<u>*13*</u>) calculate the percent recovery as:

% Recovery = (A/B) 100
A = Arc length between recovery marks at 30 seconds and 30 minutes
B = 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 (<u>*21*</u>). 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:

Percentage Elastic Recovery = (RD/OD) 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.

<u>Conclusions</u>

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/m^3.
- 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 1(e)

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 (*20*) and others studied the use of 3 to 4% (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 (*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 (*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%. Their work also showed that 2094 rubber would decrease the Marshall stability by approximately 50%.

The FDOT is scheduled to build a number or 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.

Table 6. Florida Specification for Friction Courses (4)

Property	Mixture Decimation		
	FC-1	FC-2	FC-4
Gradation Sieve Size			
1/2 in.	100	100	100
3/8 in.	---	85-100	---
No. 4	---	10-40	---
No. 10	55-85	4-12	75-90
No. 40	---	---	---
No. 80	---	---	---
No. 200	2-8	2-5	2-6
Minimum Stability (lbs)	500	---	500
Flow (.01 inches)	8-16	---	8-16
Minimum VMA (%)	15	---	15
Air Voids (%)	8-14		12-16
Minimum Eff. Asphalt Content (%)	5.5	---	5.0

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. All things considered, it is best to start conservatively when evaluating a new product.

Subtask 1(f)

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 (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

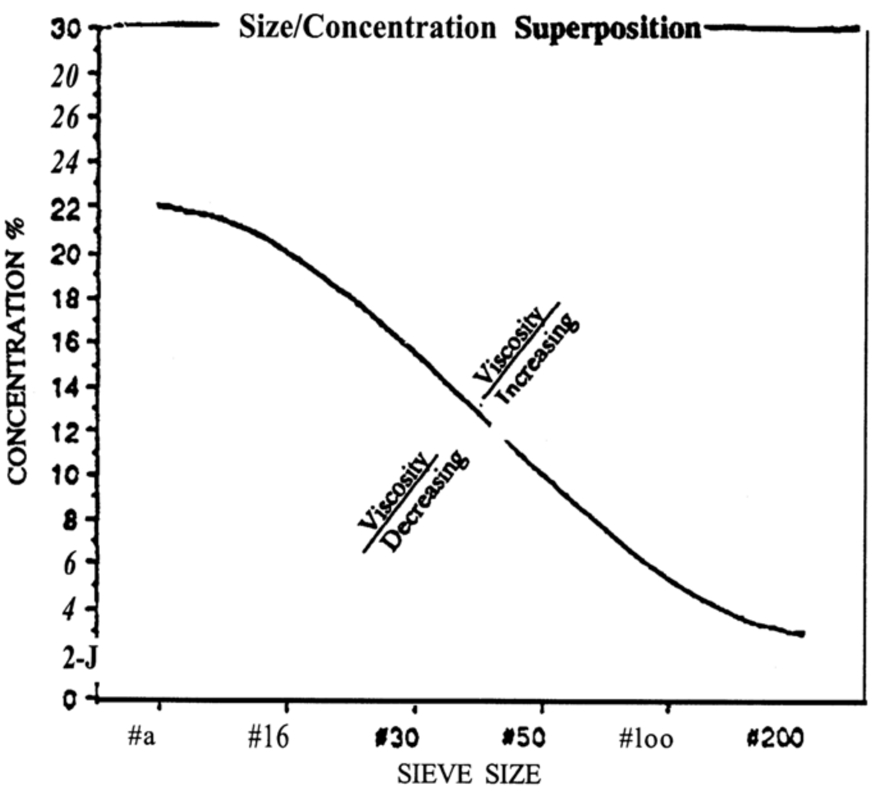

Figure 6. Size/Concentration Superposition Relationship

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 (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.

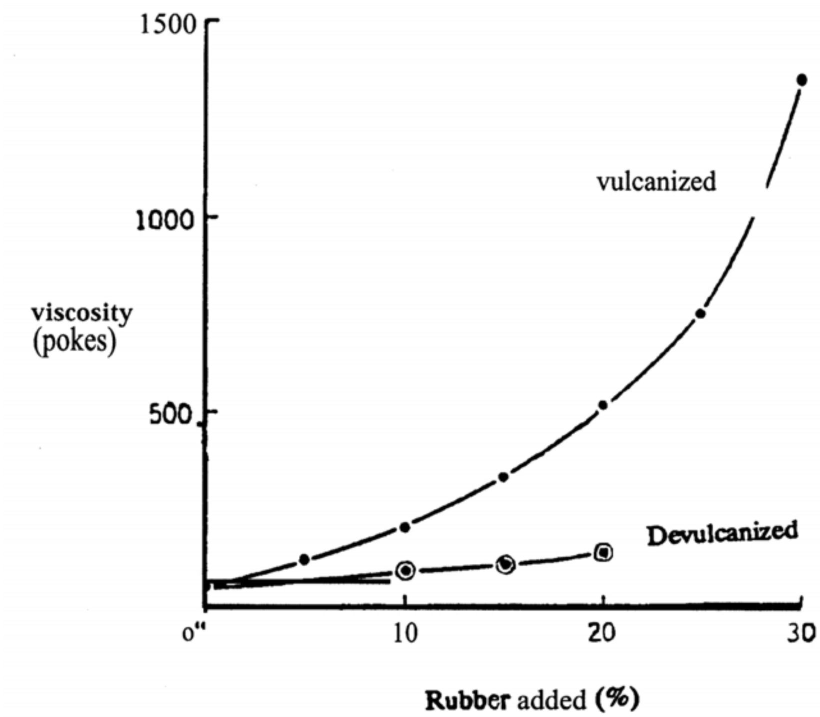

Figure 7. Effect on the Viscosity of Asphalt-Cement of Adding Ground Vulcanized Reclaimed Rubber, and Screened Devulcanized Reclaimed Rubber

Table 7. Percentage of Graded Rubber Needed for Asphalt-Rubber Blend Example

Sieve Size	% Passing	Fraction	Avg. Size	% Between	Recomm. Cone %	% Required
No. 16	100					
No. 40	90	16-40	28	10	15	1.5
No. 80	15	40-80	60	75	9	6.8
No. 200	1	80-200	140	14	4	0.6
		-200		1	4	0.0
						8.9

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 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 (3).

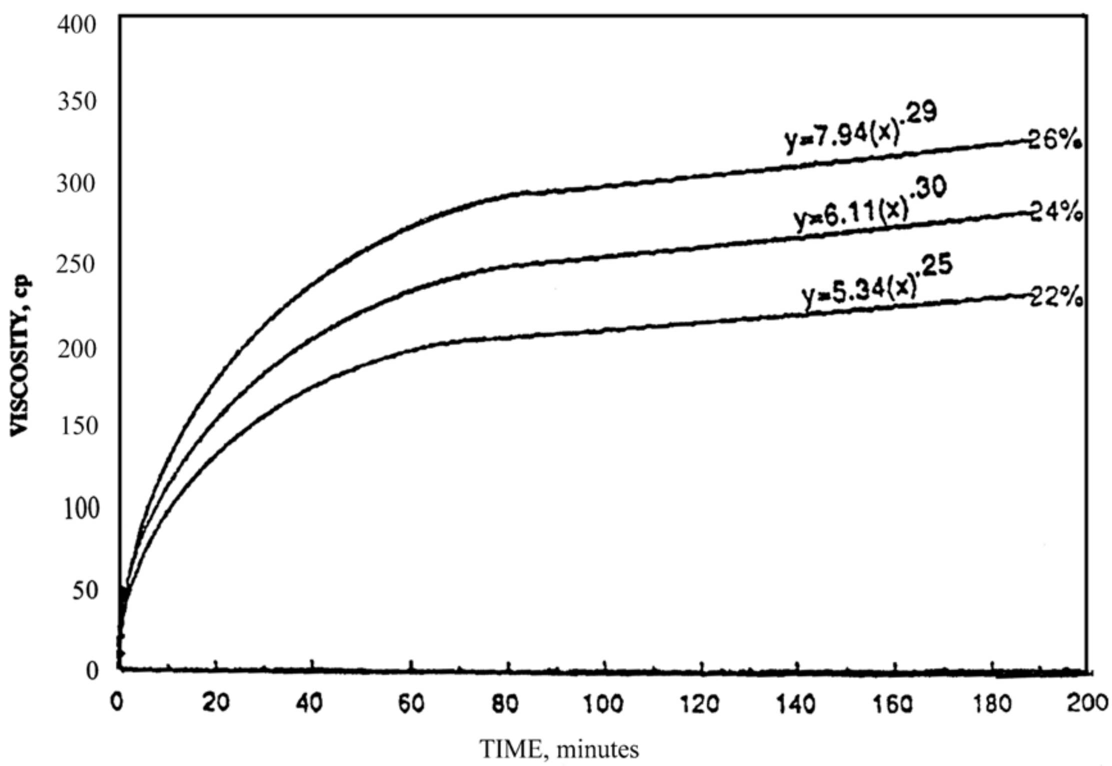

Figure 8. Effect of Digestion Time on Viscosity of Asphalt-Rubber (3)

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.

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 (*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 (*4*).

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

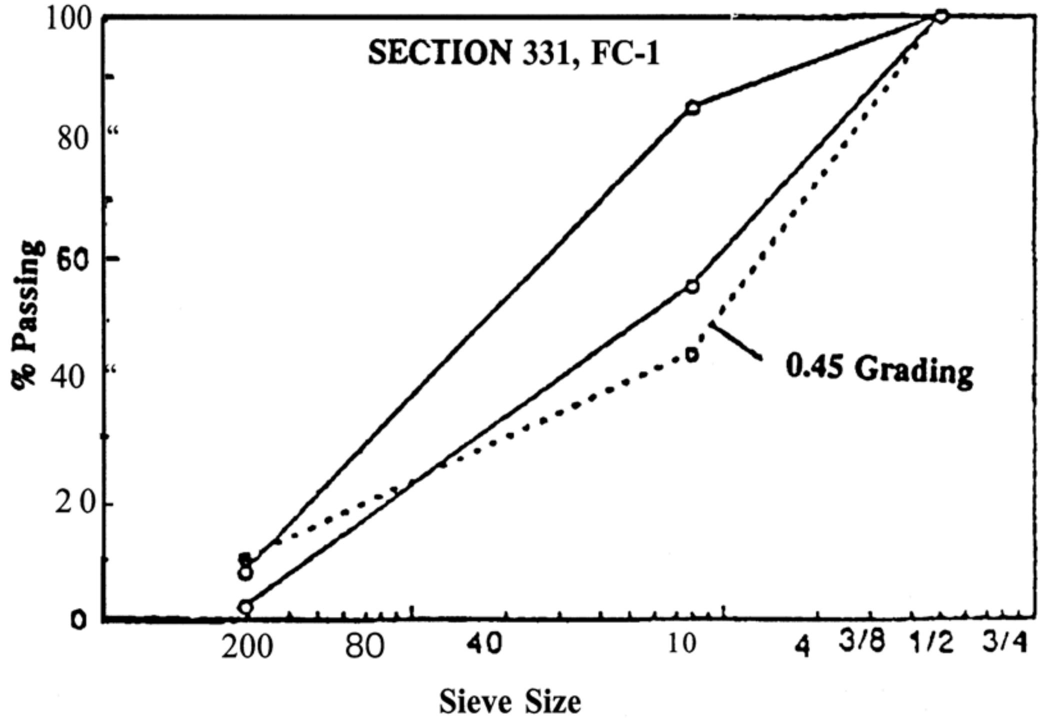

Figure 9. Florida FC-1 Grading (Dense Graded Friction Course)

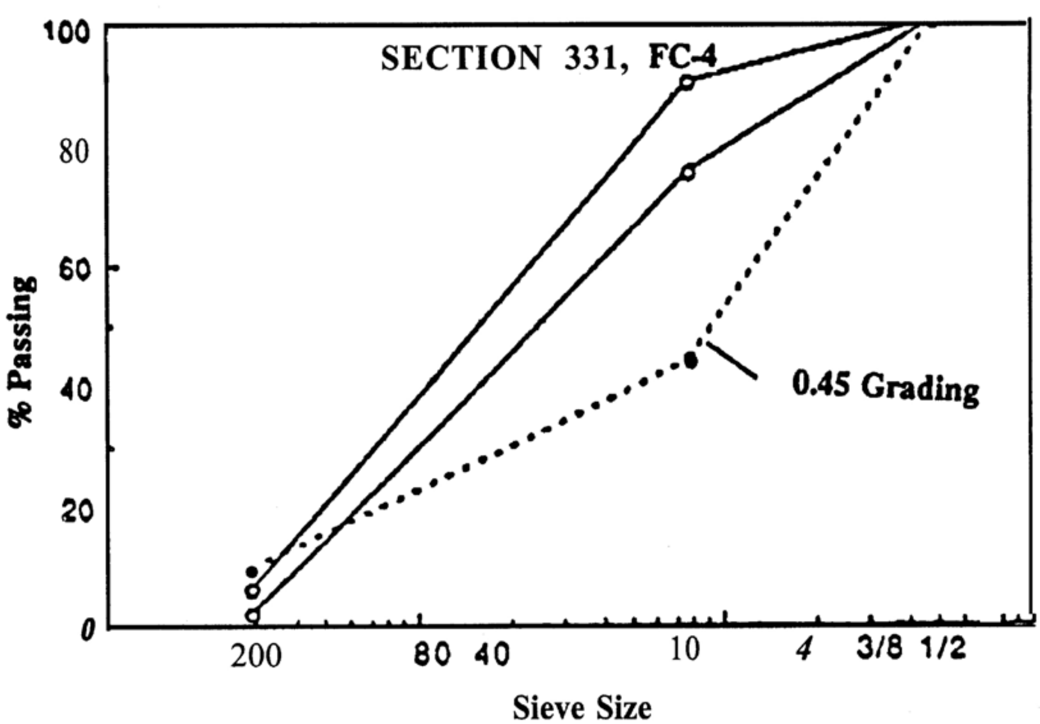

Figure 10. Florida FC-4 Grading (Dense Graded Friction Course)

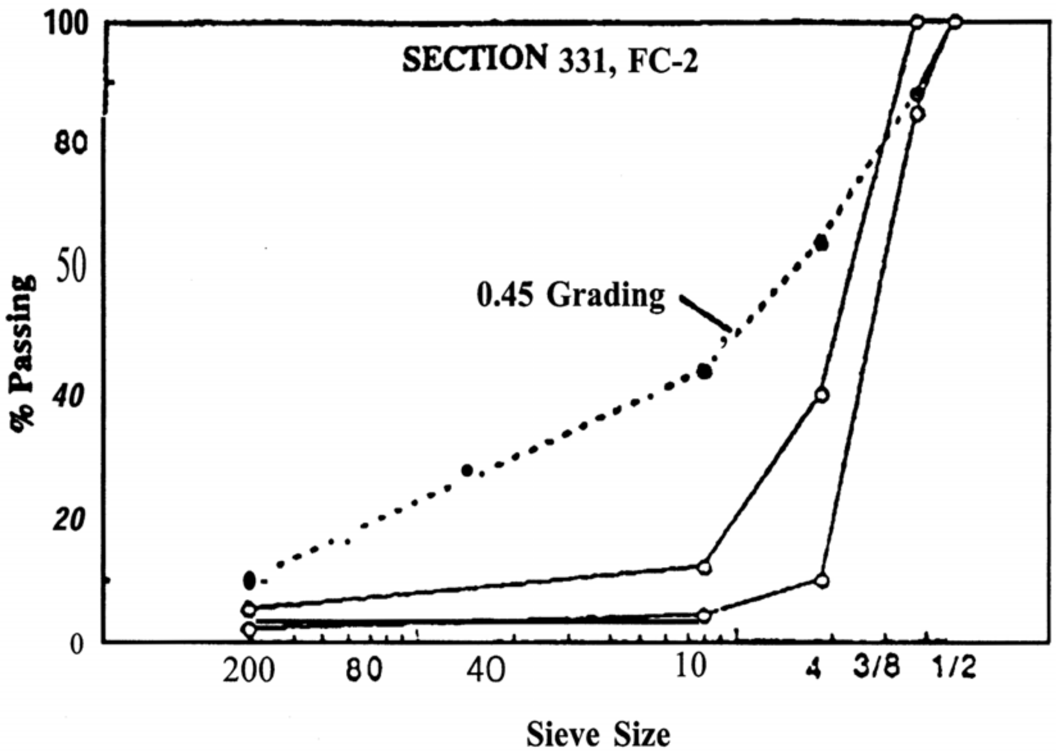

Figure 11. Florida FC-2 Grading (Open Graded Friction Course)

<u>Gradations FG1 and FG4</u>

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 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.

<u>Gradation FC-2</u>

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 (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

Property	Range
Viscosity, 140°F, P (Brookfield)	700-60,000
Viscosity, 350°F, cP (Brookfield)	1500-4000
Softening Point, R&B, F (ASTM D36), min	115 (I); 130 (II)
Cone Penetration, 77°F (ASTM D1 191), min	40 (I); 20 (II)
Resilience, 77°F (ASTM D3407), % min	15
Modulus**, psi, 39.2°F@	
0.20 seconds loading	1,000-10,000
0.50 seconds loading	600-6,000

* Contains 15-26% #10-#50 rubber by wt binder (Refs. 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.

Table 9. Suggested Marshall Criteria for Hot Mix Asphalt

Mix Type	Marshall Stability, min.	Flow, .01 in	VMA, % min.	Air Voids, %	Effective Binder, %
FC-1	500	8-18	17	8-14	6.0
FC-2	---	---	---	---	---
FC-3	500	8-18	17	12-16	5.5

Subtask 1(d)

Determine or verify the lab method of incorporation of rubber into asphalt so as to be representative of the field method of incorporation.

Laboratory Preparation of Mixtures

Note: All 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 (*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 (*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 (*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 1(i)

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.

<u>Materials</u>

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:

Viscosity, SSU, lOOF (ASTM D88), min.	2500
Flash Point, COC, F (ASTM D92), min.	390
Molecular Analysis (ASTM D2007)	
Asphaltenes, Wt. %, max.	0.1
Aromatics, Wt. %, min.	55.0

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) maybe 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:

Sieve Size	% Passing	
	A	B
#8		
#16	100	
#40	85-100	100
#80	0-20	85-100
#200	0-5	0-5

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.

<u>Preparation of Asphalt and Extender Oil</u>

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.

<u>Preparation of Asphalt-Rubber Binder</u>

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.

<u>Asphalt-Rubber Blend</u>

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.

<u>Construction</u>

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 1(n)

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

<u>Section 320-2.5 Equipment for Preparation of Bituminous Material</u>

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 2(i).

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 2(i).

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 2(i).

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 2(i).

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 2(i).

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 2(i).

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 2(i).

Section 330-10 Compacting Mixture

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

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 1(a)). Detailed specifications for ground tire rubber such as composition, gradation and chemical properties are given in Subtask 1(j). 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 l(a) and l(j).

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 1(e).

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 1(f).

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 1(f).

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 1(d) on lab method of incorporating rubber into asphalt. This mix should meet the following criteria for FC-1 and FC-4 mixes:

Mix Type	Marshall Stability, min.	Flow 0.01 in.	VMA, % min.	Air Voids, %	Effective Binder, % min.
FC-1	500	8-18	17	8-14	6.0
FC-4	500	8-18	17	12-16	5.5

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 1(f).

Section 337-5 Contractor's Quality Control

Require the contractor to run the modified extraction test (discussed in Subtask 2(g)). 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 2(g).

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 2(g).

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 2(i).

CHAPTER 3. FIELD CONSTRUCTION AND CONTROL FACTORS

Subtask 2(c)

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_{rubber}) to be added can be computed by the following formula:

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

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 2(g)

Determining the effect of the ground tire rubber in the extraction test (FM 1- T 164) which h 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°F (600°C). Dr. M. Takallou suggests ashing the material passing the 4.75 mm sieve for 4 hours at 1112°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°F (1100°C) for 30 minutes. Dunning notes that with limestones it would be necessary to recarbonate with $(NH_4)_2CO_3$. 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.

<u>Subtask 2(i)</u>

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.

<u>Binder Handling</u>

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.

Blending of these asphalt-rubber binders with lower percentage rubber is expected to take between 45 minutes and one hour to achieve the reaction necessary to provide desirable binder properties. Because of this batching requirement, a bottle-neck can easily develop during HMA production. Therefore, provision should be made at the plant to store an adequate quantity of asphalt-rubber so that disruption of HMA production does not occur.

After blending of asphalt, rubber and diluents is completed, mixing with aggregates can proceed as with conventional HMA, however temperature of the binder must remain above 350°F (recommended for high rubber contents) during the mixing and discharge operations.

Binder-Aggregate Mixing

Combining asphalt-rubber binders and aggregates should be accomplished in a central mixing plant. No difficulties should be experienced with either drum or batch type plants as long as the elevated temperatures required for preparing asphalt-rubber binders are maintained. Temperatures for dense graded mixtures should be somewhat higher than for open graded materials to achieve a uniform coating of asphalt-rubber on aggregates. Recommended binder mixing temperatures for each of these types of materials should be 325°F to 375°F for dense graded mixtures (FC- 1 and FC-4), and 275/F to 325/F for open graded mixtures (FC-2) when high rubber contents are used. Because of the higher than normal binder temperatures required for these types of mixtures, air emissions may be higher than desirable in either type of plant. At lower rubber contents the mix temperatures are likely to be lower and air emission may not be a problem.

Surge Storage

No experience has been reported with heated silo storage of hot mix asphalt-rubber. Although no difficulties should be encountered if temperatures are maintained at elevated levels, the high viscosity of these binders, and consequently mixtures, makes long term storage in silos somewhat impractical, and potentially risky. It is recommended to store mixtures for surge purposes only when using drum mixing plants until sufficient information can be obtained which indicates longer periods are practical. It is quite possible that binder drain down may occur when the open graded friction course Type FC-2 is stored for prolonged periods at high temperatures.

Transportation

Hot mix asphalt-rubber can be transported to the job site in any type of conventional rear or bottom dump truck equipped for hauling HMA. Although little data has been generated to verify temperature loss during transportation and placement, HMA fabricated with asphalt-rubber binders has been reported to lose temperature at a slower rate than conventional HMA. Similar claims have been reported by observers of HMA fabricated with other types of polymer modified binders.

Asphalt-rubber binders are significantly more viscous than conventional asphalts. Therefore, drain down of the asphalt-rubber from the aggregates to the truck bed during hauling of open graded mixtures is not likely to be as much a problem as with conventional paving grade asphalts. However, it is recommended that the truck beds be examined after open graded friction course Type FC-2 is hauled over a long distance from the plant.

After discharge of the mixtures and prior to reloading, truck beds should not be sprayed with diesel fuel or other petroleum distillates as a means of keeping the asphalt-rubber mixture from sticking to the bed. These diluents cause a reaction with the asphalt-rubber and actually promote better adhesion between the mixture and the truck bed. Instead, a mixture of lime water, soap solution or silicone emulsion should be used.

Placement

Hot mix asphalt-rubber should be placed using conventional self-propelled laydown equipment equipped with a heated screed. No apparent difficulties have been reported associated with the placement of these types of mixtures when temperatures at discharge from the screed is between 290°F to 325°F for dense graded mixes (FC-1 and FC-4) and between 275°F to 300°F for open graded mixtures (FC-2) when high rubber contents are used. Lower temperatures should be adequate for mixes containing lower rubber contents.

Compaction

Hot mix asphalt-rubber should be compacted using conventional steel wheel rollers. The hot rubber in the asphalt-rubber mixture has a tendency to stick to the rubber tires of pneumatic rollers causing the mix to pick-up, therefore rubber tire rollers are not recommended. Vibratory rollers are not recommended because of tearing and shoving which can occur in these elastic mixtures.

Compaction temperatures should be between 265°F to 300°F for dense graded (FC-1 and FC-4) and 250°F to 285°F for open graded (FC-2) mixtures. High laydown temperatures may require breakdown rolling to be postponed until the asphalt-rubber concrete can support the loads without shoving. Lubrication of the steel wheel roller drums should be by any of the solutions suggested for truck beds. Lubrication using petroleum distillates is not recommended.

Some asphalt rubber mixes (especially with high rubber contents) tend to pick-up if opened to traffic while hot. The contractor should have concrete sand on hand to be applied at approximately 1 to 2 pounds per square yard if needed to prevent pick-up.

CHAPTER 4. PAVEMENT PERFORMANCE ISSUES

Subtask 3(m)

Determine the effect on pavement performance and life of mixtures in (e) above using asphalt cement modified with ground tire rubber.

Introduction

The primary references on which this portion of the report was based includes data from projects conducted at Oregon State University (*28*), for the Alaska DOT (Ref. 29 and 30), for the Federal Highway Administration (FHWA) (*20*) and for the Federal Aviation Administration (FAA) (*31*, *32*). The asphalt-rubber materials included in the first three projects are of the rubber-modified type, i.e., the dry granulated rubber particles are mixed with the mineral aggregates prior to mixing with asphalt in quantities ranging from 2.5 to 5.5 percent by weight of the aggregates and are known by the trade name PlusRide. The concept was originated in the late 1960s by the Swedish companies Skega AB and AB Vaegfoerbaettringar (ABV) and was patented under the trade name of Rubit. This same product has been patented in the U.S. under the name PlusRide. PlusRide is marketed by Pavetech of Bellevue, Washington (*30*). The asphalt-rubber material included in the fourth and fifth references serves as the binder and consists of a blend of about 20 percent ground tire rubber and asphalt cement usually with a small amount of extender oil. This blend is reacted at elevated temperature (375-425°F) for about two hours. This material in References *31* and *32* was produced by Arizona Refining Company for a job in Victoria, Texas and is designated as asphalt-rubber.

Charles H. McDonald, consulting engineer, Phoenix, Arizona, is considered to be the father of asphalt-rubber systems developed in the U.S. Mr. McDonald's laboratory work which was initiated in 1963, resulted in the development of a patented patching material in the mid 1960s that consisted of 25910 ground scrap vehicle tire rubber and asphalt cement blended at approximately 375°F for 20 minutes. McDonald continued his experimental work with the City of Phoenix and initiated research efforts with Atlos Rubber, Inc. Several experimental test sections were placed at Phoenix Sky Harbor Airport (1966) and on U.S. 80 near downtown Phoenix. Sahauro Petroleum Asphalt Company became interested in the product and cooperated in testing seal coat type applications. In 1975 Arizona Refining Company (ARCO) began experimental work with asphalt-rubber binder systems. The result of the experimental work conducted by McDonald, Arizona DOT, Sahauro, and ARCO has led to the experimental use of asphalt-rubber in about 35 states.

Some of the significant physical and handling differences between the rubber-modified and asphalt rubber mixtures are noted below:

1. In the rubber-modified mixes, the granulated rubber represents from 2.5 to 5% of the weight of the aggregate while in the asphalt-rubber mixes the rubber usually represents about 20% of the binder or less than 1.5% of the mixture. Therefore the rubber-modified mixes use 2 to 4 times more scrap rubber than do the asphalt-rubber mixes.

2. In the rubber-modified mixes, the granulated rubber is handled like an aggregate and fed into the plant through the cold feed system while in the asphalt-rubber mixes, special blending equipment is needed as well as high temperature mixing tanks for reacting the asphalt and granulated rubber until a stable viscosity is achieved. Therefore special equipment is required for production of asphalt-rubber materials.

3. In the rubber-modified mixes the rubber particles are much larger than for the asphalt-rubber mixes. The specification for PlusRide 12 is given below.

Sieve Size	% Passing PlusRide 12 Spec.
5/8 in.	100
3/8	60-80
1/4	30-42
No. 10	19-32
30	13-25
200	8-12

When the rubber gradations from Table 3 are compared to those above, it should be noted that all the rubber particles in Table 3 for use in asphalt-rubber pass the No. 8 sieve while less than 40% pass the No. 10 for the PlusRide rubber specification.

In addition the largest of the particles in PlusRide rubber are much coarser than the coarsest aggregates in the Florida FC- 1 and FC-4 dense graded surface mixes and while the rubber is not coarser than the aggregate in the FC-2 open graded mix it does occur in much larger quantities than the coarsest aggregate particles, compare to Table 6 (4).

Pavement Performance

One of the primary considerations in the inclusion of scrap tire rubber into Florida's HMA surfaces, is that there should be no detrimental effects on performance, i.e., the quality of the current mixes should not be compromised in order to dispose of the scrap tire rubber. This section of the report deals with several properties of mixtures that are affected by the inclusion of scrap rubber and that relate directly to the performance of these mixtures. It should be remembered that experience with both the rubber modified (PlusRide) and the asphalt-rubber systems is based on research studies that used volumes of rubber that are many times larger than that proposed by the FDOT, therefore, the NCAT researchers will be required to make judgments about the effects of the smaller quantities of rubber proposed by the FDOT. It should also be noted that laboratory test results are often used to infer field performance, but relationships between laboratory test results and actual field performance may not be accurate.

Fatigue Resistance

Fatigue resistance is the ability of a material to resist repeated loads that induce tensile strains which lead to cracking. The Florida surface mixes are typically 1 to 1-1/2 inches thick and are most often placed as overlays on existing roadways. If these roadways show severe cracking due to overloading, the existing surface is milled off and a structural layer is placed to strengthen the pavement sufficiently to withstand the anticipated traffic, and finally a FC-1 or FC-4 surface is placed if the roadway is a two lane facility or a multi-lane facility with speeds lower than 50 mph. A FC-2 open graded friction course is placed as the surface on all multi-lane facilities with speeds of 50 mph or greater.

When rubber particles are added into a HMA using either the rubber-modified or the asphalt-rubber technology, the fatigue life is significantly improved. All the studies involving laboratory prepared mixes referenced above as well as the field placed materials tested and reported in Reference 20 show improvements when rubber is added. In fact in Reference 33, Piggott and

Woodhams conclude that the addition of 5% rubber to the asphalt in HMA systems probably doubles the fatigue life of the roadways. It should be noted that laboratory tests results are not directly translated to actual field performance. Therefore, while improvements in the field would be expected, the magnitude of field performance improvements would likely be much lower than the laboratory test results indicate.

Improvements in fatigue resistance for rubber modified mixes are shown in Figures 12 and 13 for laboratory prepared materials and in Figures 14 and 15 for field mixed and placed but laboratory tested materials. The details describing these studies may be found in References 20 and 28, however, the point to be made here is that when compared to the control mixes, the rubber-modified mixes all show superior fatigue resistance. In Figures 12 and 13, the control mix is designated as T, showing 0% rubber. In all cases the rubber-modified mixture fatigue curves are located above the control mixes, showing that for a given strain, the number of repetitions to failure (fatigue life) is always higher for the rubber-modified mixes than for the control mix. In fact, these differences are more pronounced at 21°F (Figure 13) than at 50°F (Figure 12). Notice also that at 21°F (Figure 13) the dense graded mix N has better fatigue resistance than the gap-graded mix A while at 50°F (Figure 12) the opposite is true.

For the field mixed and Reference 20, the fatigue compacted samples which were cored from the roadway studied in plots in Figures 14 and 15 show that the rubber-modified materials exhibited a higher fatigue life than the control mixes. In fact if the curves from Figure 14 were superimposed on Figure 15, the rubber-modified mixture curves would all be located above the control mix curves. In addition, the slope of the fatigue curves for the control mix is steeper than for the rubber-modified mix indicating a lower fatigue resistance at low strains, those below 150 micro inches/inch.

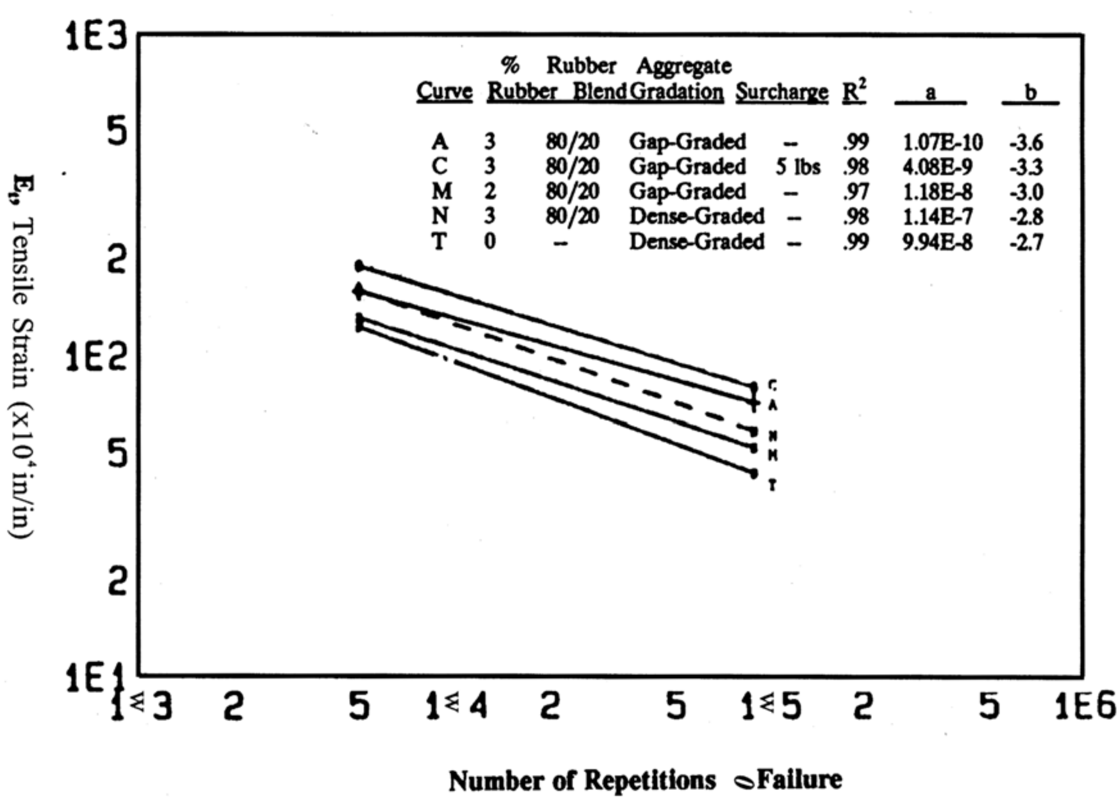

Figure 12. Laboratory Fatigue Curves at 50°F (28)

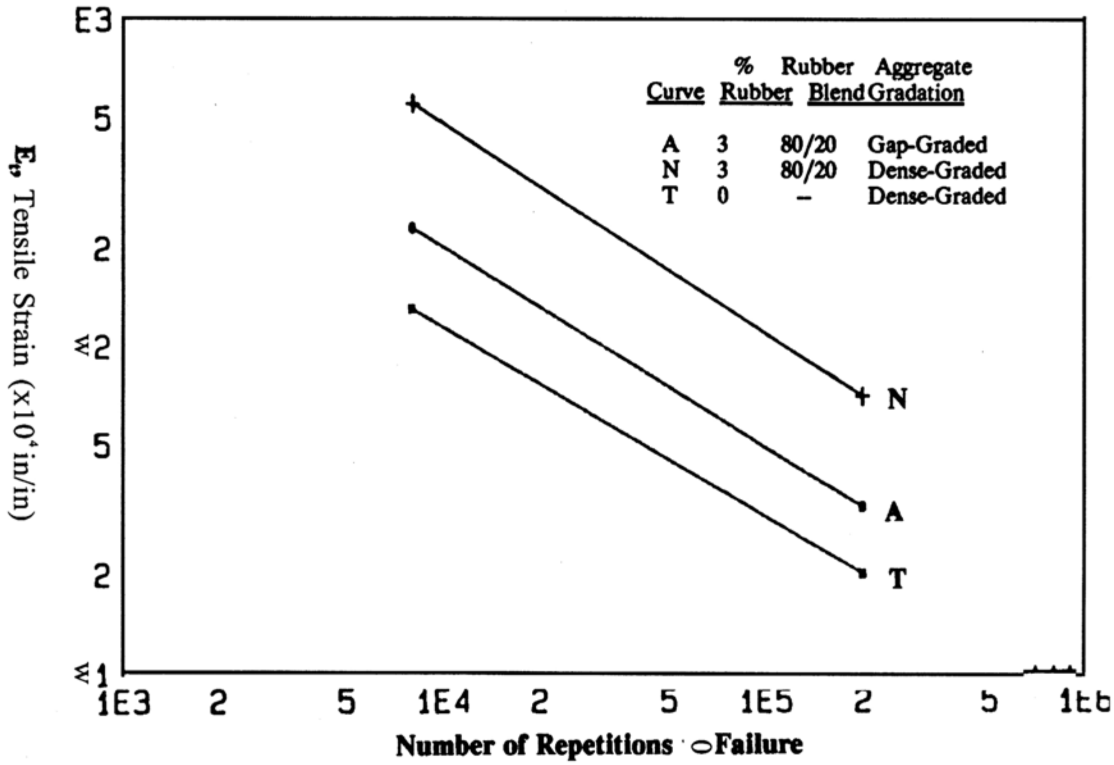

Figure 13. Laboratory Fatigue Curves at 21°F (*28*)

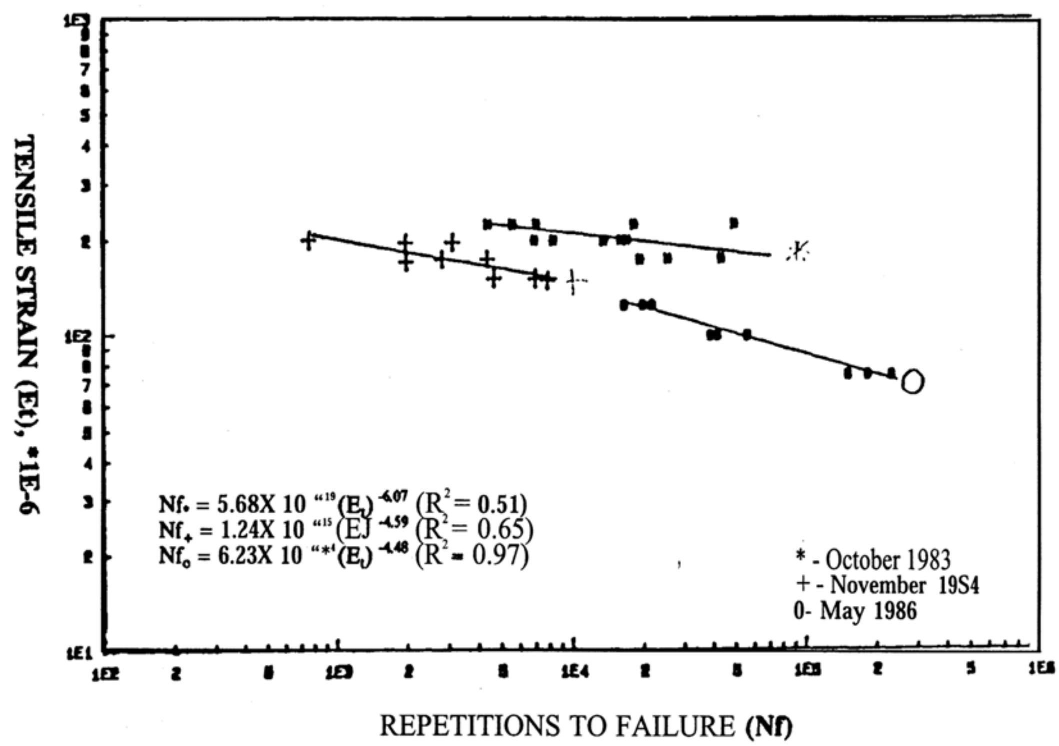

Figure 14. Tensile Strain vs. Fatigue Life, Rubber Samples (*20*)

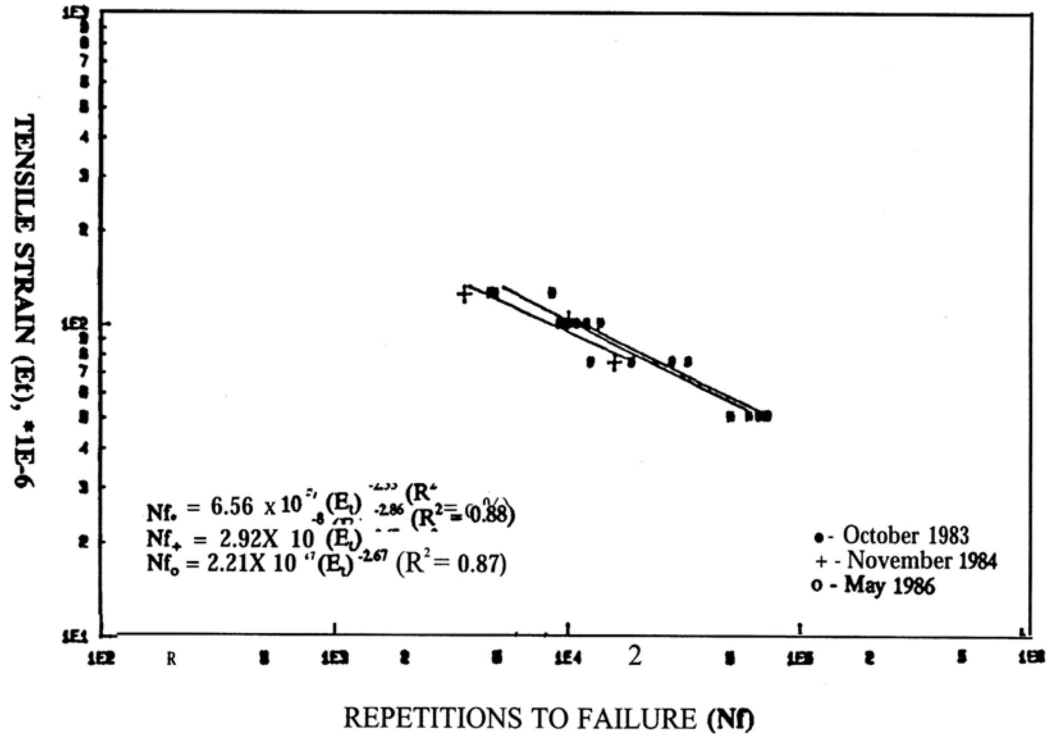

Figure 15. Tensile Strain vs. Fatigue Life Control Samples (20)

For the asphalt-rubber mixes reported in Reference 31, only one blend of asphalt-rubber was studied: 80% asphalt cement (77%) and extender oil (3%) and 20% rubber. Beam fatigue tests were performed on an aggregate mixture which met the FAA dense graded HMA specifications prepared with an AC-10 (4.8% asphalt) control and the asphalt-rubber binder at three different levels: ARC-Low (4.23% binder), ARC-Medium (4.73% binder) and ARC-High (5.23% binder). The rubber basically fit within the grading band for Type II rubber in Table 3.

The laboratory fatigue test results are shown in Table 10. The regression equations were for the fatigue equation of the form:

$$N_f = K_1 (1/\varepsilon_t)^{K2}$$

When N_f = number of repetitions of load to failure
ε_t = induced tensile strain, in/in
K_1, K_2 = regression constants

This equation is a straight line on a log-log plot of cycles of failure versus bending strain, where log K_1 is the intercept of the y-axis and minus K_2 is the slope of the straight line. The value of the parameters, K_1 and K_2 are influenced by factors such as the type of loading, dimensions of the test specimen, loading rate, test type, temperature, and properties of the mix including air voids, aggregate gradation and type, and binder content and viscosity, etc. Thus, K_1 and K_2 are not material properties but rather model parameters determined from regression analysis.

Table 10. Material Parameters Calculated from Laboratory Beam Fatigue Tests (*31*)

Material	Temperature °F	Number of Samples	R	K_1	K_2	$\log K_1$
AC-10 Control	104	8	-0.89	3.21×10^{-3}	2.35	-2.49
	68	8	-0.95	9.48×10^{-U}	4.69	-11.02
	34	7	-0.63	1.43×10^{4}	2.92	-5.85
ARC-Low	104	10	-0.96	2.72×10^{-6}	3.38	-5.57
	68	9	-0.92	1.03×10^{4}	3.17	-5.99
	34	7	-0.93	4.47×10^{U}	4.48	-11.35
ARC-Medium	104	10	-0.85	2.82×10^{4}	3.47	-5.55
	68	9	-0.98	3.16×10^{-5}	2.82	-4.50
	34	9	-0.86	9.91×10^{-10}	4.04	-9.00
ARC-High	104	10	-0.91	1.02×10^{4}	2.95	-3.99
	68	10	-0.99	4.90×10^{4}	2.52	-3.31
	34	8	-0.81	3.82×10^{-7}	3.19	-6.42

In order to make use of the laboratory data included in Table 10 in a comparative analysis which would be sensitive to both material and temperature differences, a double regression analysis was performed using the laboratory data. The first regression analysis was performed to develop a set of equations (one for each of the four mixes tested) where temperature was the independent variable and K_1 was the dependent variable. A second set of regressions were performed to develop a relationship between K_2 and log K_1 with log K_1 as the independent variable. Using this set of equations (Table 11), fatigue parameters could be calculated for any temperature chosen.

Table 11. Regression Equations Developed to Predict K_1 and K_2 for any Temperature for Control and Asphalt-Rubber Mixes (*31*)

	log K_1 vs. log T (°F)	
AC-10 Control	*log K_1* =	14.630-4.558 log T
ARC-Low	*log K_1* =	20.483-7.879 log T
ARC-Medium	*log K_1* =	20.483-7.879 log T
ARC-High	*log K_1* =	14.466-5.516 log T
	K_2 vs. log K_1	
AC-10 Control	*log K_1* =	1.512-0.280 (log K_1)
ARC-Low	*log K_1* =	2.052-0.213 (log K_1)
ARC-Medium	*log K_1* =	1.900-0.243 (log K_1)
ARC-High	*log K_1* =	2.033-0.187 (log K_1)

In the FAA study, the temperatures were chosen to represent the seasons of four environmental zones and the regression parameters calculated from the equations in Table 11 are shown in Table 12.

The last column in Table 12 contains estimates of the fatigue life, Nf , for a strain of 100 micro-inches/inch. Notice that, for the ARC-medium and ARC-high mixes, as the temperature exceeds 60°F, the performance of the asphalt-rubber mixes is superior to that of the AC-10 control but

Table 12. Fatigue Equation Parameters (K_1 and K_2) at the Seasonal Temperatures for Each Environmental Zone for Control and Asphalt-Rubber Mixes (ARC) (<u>31</u>)

Material	Temperature °F (°C)	K_1 (Not Adjusted to Field Conditions)	K_2	N_f, when , = 10^3 in/in
AC-10 Control	35 (1.7)	2.56 x 10^{4}	3.64	2,130
	50 (10.0)	1.30 x 10^{7}	3.43	2,530
	60 (15.6)	2.99 x 10^{-7}	3.34	3,130
	75 (23.9)	8.26 x 10^{-7}	3.21	3,520
	90 (32.2)	1.90 x 10^{4}	3.11	4,060
	105 (40.6)	3.83 x 10^{4}	3.03	4,710
ARC-Low	35 (1.7)	1.77 x 10^{11}	4.34	190
	50 (10.0)	1.52 x 10^{-9}	3.93	940
	60 (15.6)	1.48 x 10^{4}	3.72	2,140
	75 (23.9)	2.41 x 10^{-7}	3.46	5,780
	90 (32.2)	2.35 x 10^{4}	3.25	13,200
	105 (40.6)	1.61 x 10^{-5}	3.07	26,100
ARC-Medium	35 (1.7)	4.81 x 10^{9}	3.92	2,770
	50 (10.0)	7.99 x 10^{4}	3.62	5,790
	60 (15.6)	3.36 x 10^{-7}	3.47	8,640
	75 (23.9)	1.95 x 10^{4}	3.29	14,500
	90 (32.2)	8.20 x 10^{4}	3.13	20,100
	105 (40.6)	2.76 x 10^{-5}	3.01	29,600
ARC-High	35 (1.7)	1.12 x 10^{4}	3.14	2,950
	50 (10.0)	8.03 x 10^{4}	2.98	1,990
	60 (15.6)	2.20 x 10^{-5}	2.90	11,000
	75 (23.9)	7.52 x 10^{-5}	2.80	18,900
	90 (32.2)	2.06 x 10^{4}	2.72	29,800
	105 (40.6)	4.81 x 10^{4}	2.65	42,900

for temperatures lower than 60°F the performance for all mixes except ARC-low is about the same. The poor low temperature performance of the ARC-low mix will be ignored since it is highly unlikely that materials would be placed at such a low binder content.

One other study involving rubber percentages similar to those in the asphalt-rubber mixtures was reported in Reference <u>33</u>. In this study, the reclaimed rubber was added with the hot aggregate directly into either the pugmill in the field or the mixer in the laboratory, the aggregate and rubber were mixed for 10 to 15 seconds and then the hot asphalt was added and mixed for 45 seconds at about 340°F. Rectangular beams were compacted and fracture characteristics measured. The authors concluded that the addition of the reclaimed rubber improved the durability and crack resistance of the mixtures especially at low temperatures.

In reviewing the data from these studies, it appears that adding the granulated rubber to the hot aggregate without reaction time between the asphalt and rubber, produces a mixture with fatigue characteristics that are superior to conventional HMAs especially at low temperatures. However, the data from the asphalt-rubber studies in Texas indicate that the low temperature fatigue resistance is not affected but that improvements in high temperature fatigue result when asphalt rubber binders are used.

It is difficult to make direct high temperature fatigue comparisons between asphalt-modified and asphalt-rubber mixes since the highest test temperature reported for References *20* and *28* through *30* is either 50°F or 73°F while the results in Reference *31* included temperatures up to 105°F. And even though the dense graded asphalt modified mix (N in Figure 12) showed a significant increase in fatigue life at 50°F as compared to the dense graded control mix T in Figure 12, the trend in fatigue life improvement for the rubber-modified mixes appears to be lower at higher temperature (compare Figure 13 and 12 curves). The opposite trend is apparent for the asphalt-rubber mixes included in Table 12.

Therefore, for hotter conditions in Florida, it appears that the asphalt-rubber binders would give better fatigue resistance than the rubber-modified mixtures. It should be noted, however, that the fatigue resistance of both types of mixes is better than the control dense graded HMA mixtures.

Resilient Modulus

Resilient modulus tests of all HMA mixes included in these discussions were performed on either field cores or laboratory prepared cylindrical specimens tested in indirect tension. The resilient modulus is the ratio of the repeated axial deviator stress to the recoverable axial strain.

The Reference *28* and *30* study involved evaluation of the properties of twenty different mix combinations including the three rubber blends described in Table 13. As part of that study resilient modulus measurements were made at 50/F to evaluate the effect of several factors on those measurements. Figure 16 shows both the effect of rubber gradation on resilient modulus as well as the effect of rubber content on resilient modulus. The mixes used to develop the data in Figure 16 were gap graded as shown in Table 14. It can be noted from these barographs that as the rubber gradation changes from coarse to fine, the resilient modulus for this gap graded mix increases toward that measured for the dense graded control mix of 1,100 ksi. Additionally, as the percent rubber decreases from 3 to 2%, the effect of the rubber gradation is greatest for the more finely ground rubber. The data in the bar graph shows two distinct trends for the two percentages of rubber. At 3% rubber, the rubber blend that optimizes resilient modulus appears to be the medium blend which consists of 60% coarse and 40% fine rubber (Table 13). At 2%

Table 13. Rubber Gradations for the Coarse and Fine Rubbers and the Three Rubber Blends (*28*)

Sieve Size	Scrap Rubber Gradation		Rubber Blend		
	Coarse	Fine	Coarse (80/20)	Medium (60/40)	Fine (0/100)
1/4 in	100		100	100	
No. 4	97		97.6	98.2	
No. 10	15	100	32	49	100
No. 20	4	86	20.4	36.8	86
No. 40	3	30	8.4	13.8	30

rubber, the trend of resilient modulus continues to increase as the rubber gradation goes from coarse to fine; perhaps indicating that as the percent rubber decreases the modulus is affected most by the finer rubber gradations. The conclusion drawn by Piggott and Woodhams appear to confirm this trend as they indicated that limited evidence suggests that an average particle size near the No. 30 sieve provides the best results (33).

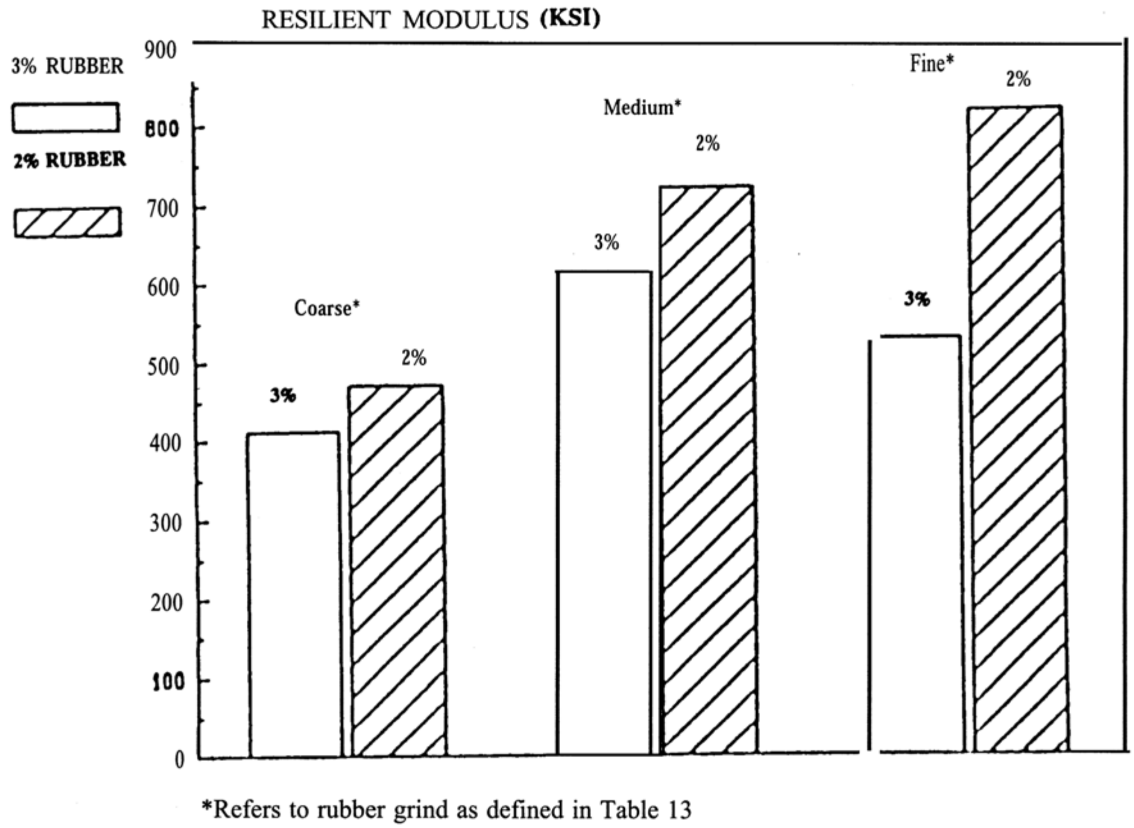

Figure 16. Effects of Rubber Content on Resilient Modulus at 50°F for Gap-Graded Asphalt

Table 14. Aggregate Gradation for the Gap and Dense Graded Mixtures Used in References 20 and 28

Sieve Size	% Passing	
	Gap Graded	Dense Graded
3/4 in	---	100
5/8	100	---
3/8	70	76
1/4	37	---
No. 4	---	55
No. 10	26	36
No. 30	18	---
No. 40	---	22
No. 200	10	7

The Reference *29* study for the Alaska DOT included resilient modulus tests on specimens prepared using materials from two roadway projects: Peger Road and Huffman Road. For the Peger Road project three different rubber percentages (2.5, 3.0, and 3.5%) were incorporated into a gap graded aggregate. Table 15 contains a summary of the resilient modulus data for Peger Road and shows that the highest average resilient modulus occurred at 2.5% rubber for the standard mix. However, when the standard mix with 3.5$% rubber had 2% of fine rubber added to it, the modulus increased by 60%. Table 16 contains a summary of the resilient modulus results for Huffman Road where the aggregate mixture gradations varied from fine to coarse with each of the three gradations having an extra 296 fine rubber added to the. standard mix. Results in Table 16 indicate that not only did the finer gradation of the standard mixtures exhibit the largest average resilient modulus but also it was the mixture which showed the greater percentage and absolute increase in resilient modulus with the addition of 2% fine rubber. Since no values were reported for the hot mix asphalt control mixture, no comparison can be made between conventional HMA and rubber-modified hot mix.

Table 15. Resilient Modulus Summary for Mixes Placed on Peger Road (*29*) - 50°F, 200 Microstrain

a) 8.0% AC-5, 25% Rubber (80/20)

(A) Standard Mix (1)			(B) Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
1	149		10	188		
2	130	154	11	223	190	+23.3
3	180		12	158		

b) 8.0% AC-5, 3% Rubber (80/20)

(C) Standard Mix (1)			(C) Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
4	134		13	153		
5	151	133	14	76	163	+22.6
6	113		15	173		

c) 8.0% AC-5, 3.5% Rubber (80/20)

(E) Standard Mix (1)			(F) Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
7	115		16	204		
8	115	127	17	193	205	+61.4
9	152		18	217		

Notes: (1) Cores 1-9, standard mix and compaction procedures
(2) Cores 10-18, 2% fine rubber in addition to blend.
Mixes are cured @ 204°F (400°F for 45 minutes.
Standard compaction.

Table 16. Huffman Road Materials Resilient Procedures Summary (*29*) - 50°F, 200 Microstrain

a) 9.7% AC-5, Coarse Aggregate Gradation

Standard Mix (1)			Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
1	135		10	74		
2	80	92	11	125	97	+5.4
3	61		12	93		

b) 7.0% AC-5, Fine Aggregate Gradation

Standard Mix (1)			Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
4	204		13	326		
5	200	206	14	314	329	+59.7
6	213		15	347		

c) 8.0% AC-5, Middle Aggregate Gradation

(G) Standard Mix (1)			(H) Modified Mix (2)			% Increase in Avg. Modulus
Sample Number	Modulus, Ind.	ksi Avg.	Sample Number	Modulus, Ind	ksi Avg.	
7	126		16	134		
8	91	112	17	193	177	+59.0
9	118		18	205		

Notes: (1) Cores 1-9 have 3% (80/20) with standard mix and compaction procedures
(2) Cores 10-18 have 3% rubber (80/20) plus 2% fine rubber. Mixed and cured at 204°F (400°F for 45 minutes. Standard compaction.

A comparison was presented in Reference *20* for the control mix and the rubber-modified mixture containing 3% coarse rubber. The resilient modulus values reported in Figure 17 show that the rubber modified mixtures exhibit a resilient modulus about 75% of the control mixture for the complete time period shown by the data.

For the asphalt-rubber mixture included in Reference *31*, the relationship between resilient modulus and materials included in the project is shown in Figure 18. Just as was reported for the rubber-modified mixture, the asphalt-rubber mixes show that at lower temperatures the control mix has the highest modulus but at temperatures above 75°F the asphalt-rubber mixes exhibit higher modulus values. In fact, at 105°F, the lowest resilient modulus shown in Figure 18 is for the control mixture. At the higher temperatures, the higher resilient modulus of the asphalt-rubber mix allows the pavement to sustain a lower tensile strain at a given load. This lower strain coupled with the higher fatigue life shown in Table 12 should make the asphalt-rubber mixtures better than the rubber-modified mixes for Florida's environment.

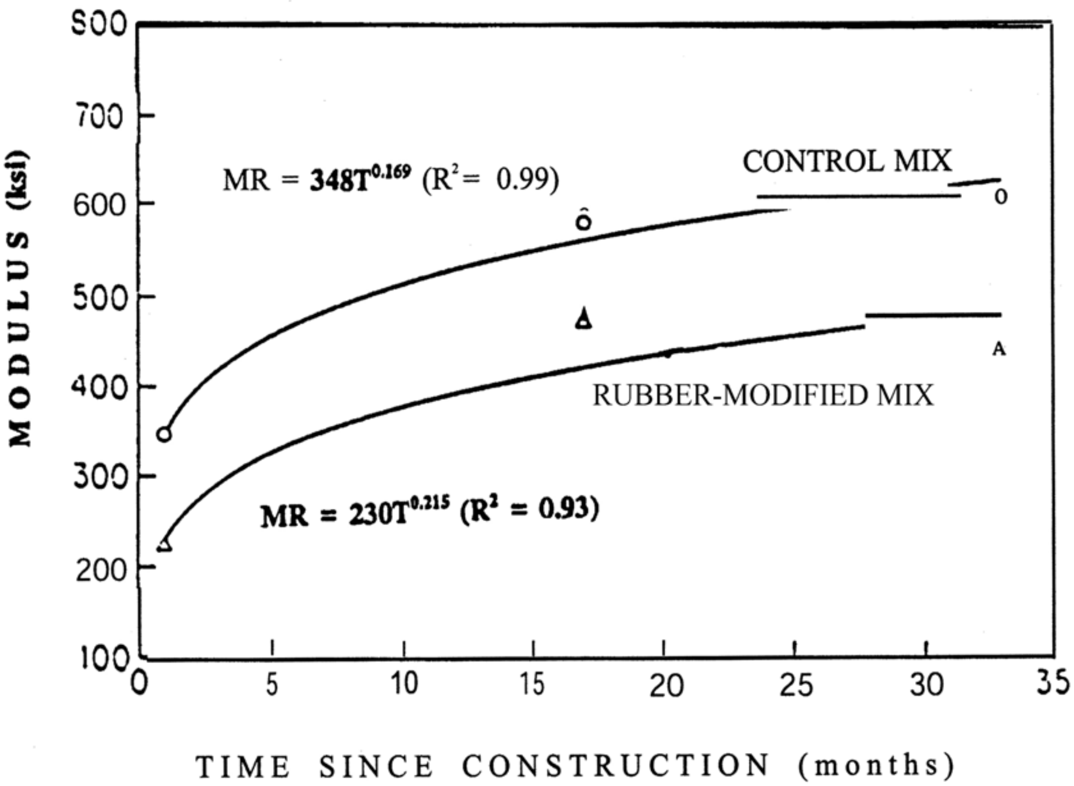

Figure 17. Variation of Resilient Modulus with Time After Construction for a 3% Coarse Rubber Modified Mix and the Control HMA (*20*)

Permanent Deformation

Very little experimental work has been done to either research the creep and permanent deformation characteristics of asphalt and rubber systems or to estimate the rutting performance of these mixes as compared to control HMA mixes. In the literature cited, only the projects reported in References *28* and *31* included any evaluation of creep characteristics of asphalt and rubber systems.

Figure 19 (*28*) contains plots of creep behavior of rubber-modified mixes and shows that as the loading time increases all rubber-modified mixes experience significantly more vertical compressive strain than the control mix (Mix T). Figure 19 also shows that these same rubber-modified mixes compress much more at higher temperature (104°F) than does the control mix. This means that under slow moving or parked vehicles, these rubber-modified mixes will experience significantly greater permanent compressive strain than would conventional HMA mixtures.

Notice that of the rubber-modified mixes, the dense graded mix (N) and the gap graded mix with the 100% fine rubber (I) have the flattest slopes at the 104°F test temperature. This indicates that both the dense grading on the aggregate and the fine rubber gradation improve the creep resistance of the rubber-modified mixes. The best overall creep resistance at both temperatures is shown by the dense graded control HMA.

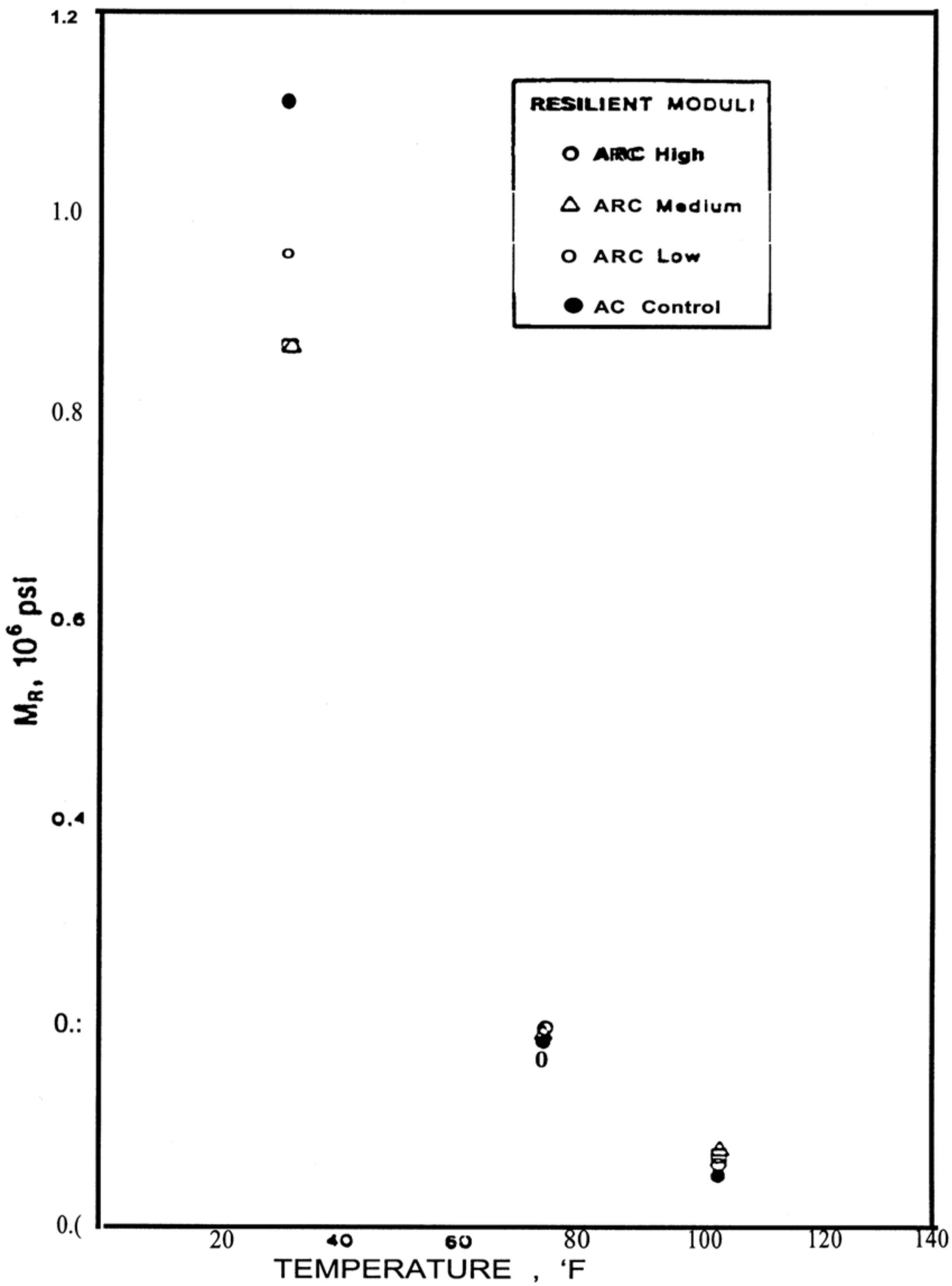

Figure 18. Plot of Resilient Modulus vs. Temperature for Both the Control and Asphalt-Rubber Mixtures from Reference _31_

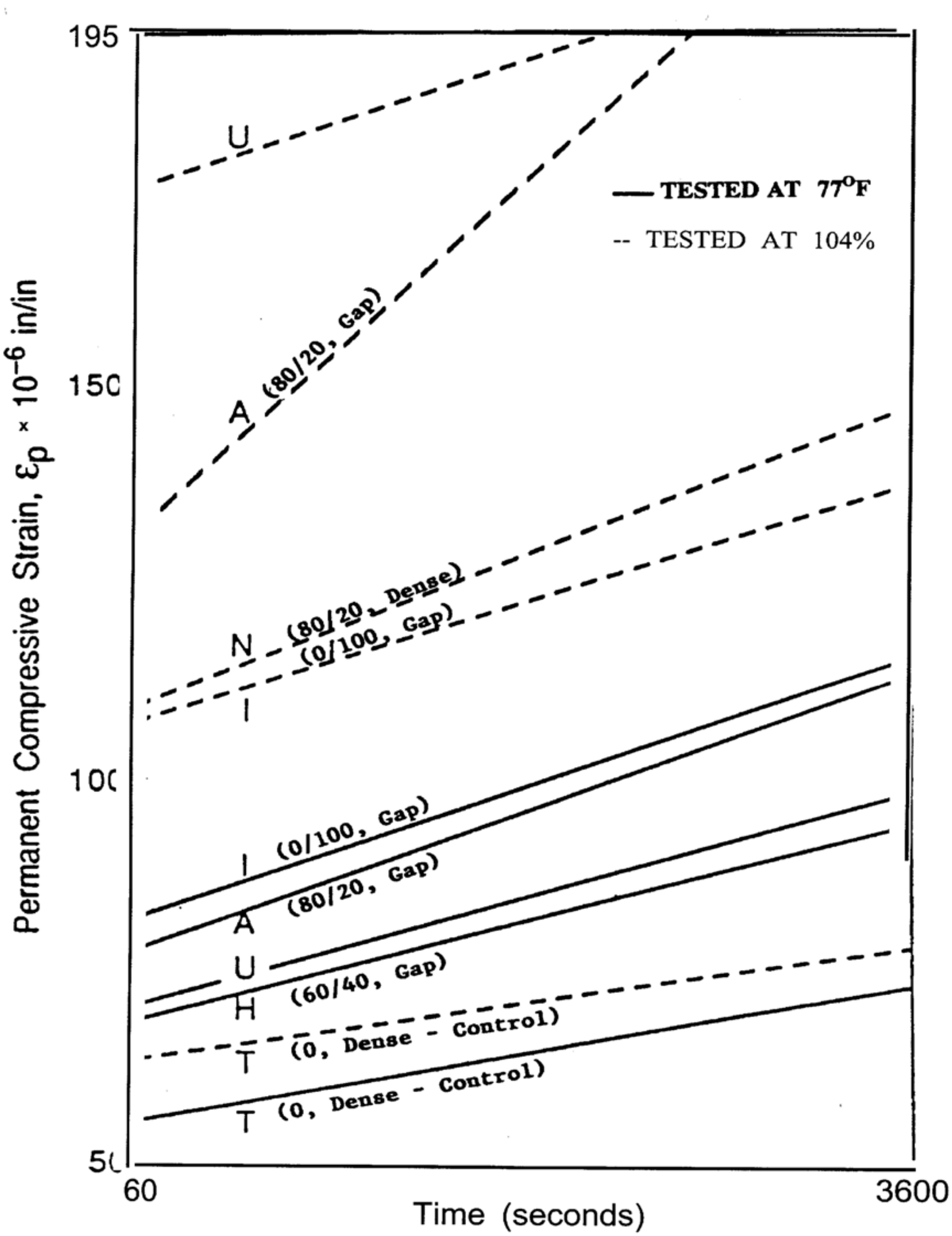

Figure 19. Creep Behavior of Both Rubber Modified Mixes at 3% Rubber and the Control HMA (28)

Creep under constant load is one of the considerations in evaluating the rutting potential of asphalt mixtures, however, the behavior of the mixtures under repeated load is also very important. Figure 20 is a plot of five of the mixes from Figure 19 that were subjected to repeated load where the permanent compressive strain was measured. This plot shows that under repeated cyclic load, the slopes of the permanent strain lines for all the rubber-modified materials are lower than the slope of the control HMA (line T). Therefore, while the rubber-modified mixes deform more under constant load than the control mix, they deform less than the control mix under repeated load.

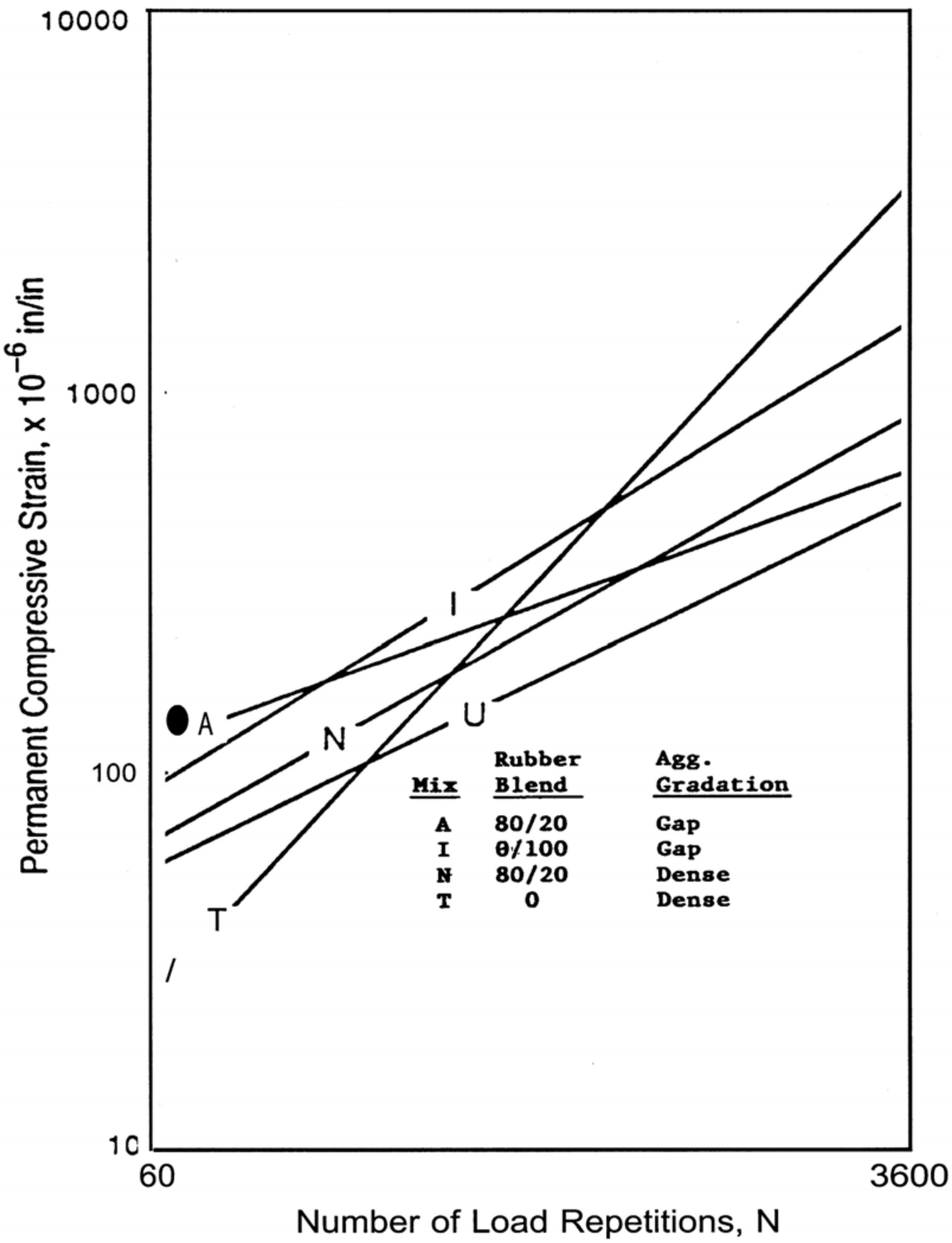

Figure 20. Relationship Between Number of Load Repetitions and Vertical Strain for 3% Rubber Modified Blends and the Control HMA at 104°F (28)

This superior permanent deformation performance was also reported as part of the FAA asphalt-rubber study (*31*). Table 17 contains the results of an analysis conducted using creep data from the three asphalt-rubber mixes and the control HMA which was input into a modified version of ILLIPAVE to predict the development of rutting of airfield runway pavements. In Table 17 the column titled year corresponds to the year during which the predicted rut depth exceeded 0.7 inches. The absolute magnitude of the numbers is not what is important for use in this study but rather the relationship between the times when the rutting first exceeded 0.7 inches. Notice that for the wet/no freeze zone, which corresponds to the environmental zone of Florida, the asphalt-rubber mixes performed significantly better than did the conventional HMA control mix. In fact, significant rutting problems are predicted for the control mix but not for any of the asphalt-rubber mixes. The only environmental zone in which the performance of the control mix approaches that of the asphalt-rubber mixes is the dry/no freeze. It should be noted that in Florida AC-30 are used and not AC-10 asphalt cements as was used in the FAA study. The substitution of AC-30 asphalt for AC-10 will make all types of HMA more resistant to permanent deformation and had AC-30 asphalts been used in the preceding analysis substantially lower permanent deformation would be expected for the control mix. However, no major changes in predicted permanent deformation would be expected for the asphalt-rubber mixes because of the techniques used to formulate the asphalt-rubber.

Table 17. Predicted Service Life Before Rut Depths Reached 0.7 in. For Various Materials and Environmental Zones (*31*)

Zone (Seasonal Temperature °F)	Material	Year	Rut Depth (First Rut Depth over 0.70 in.)	Damage Index (Field Fatigue Parameters)
Wet/Freeze (35-65-95-60)	AC-10 Control	04	0.71	0.020
	Asphalt-Rubber, Low	17	0.73	0.050
	Asphalt-Rubber, Med.	17	0.70	0.027
	Asphalt-Rubber, High	17	0.76	0.038
Dry/Freeze (35-60-90-50)	AC-10 Control	05	0.73	0.017
	Asphalt-Rubber, Low	18	0.72	0.054
	Asphalt-Rubber, Med.	18	0.72	0.025
	Asphalt-Rubber, High	17	0.72	0.033
Wet/No Freeze (75-95-105-95)	AC-10 Control	1	1.61	0.019
	Asphalt-Rubber, Low	13	0.70	0.062
	Asphalt-Rubber, Med.	15	0.72	0.060
	Asphalt-Rubber, High	13	0.75	0.045
Dry/No Freeze (55-75-95-75)	AC-10 Control	15	0.75	0.201
	Asphalt-Rubber, Low	16	0.73	0.083
	Asphalt-Rubber, Med.	16	0.71	0.038
	Asphalt-Rubber, High	15	0.73	0.038

Based on this limited set of data, it is the opinion of the NCAT researchers that the permanent deformation characteristics of both the rubber-modified and asphalt-rubber mixes are better than the conventional HMA materials they replace.

Marshall Mixture Design Properties

The Marshall mixture design method includes several properties of asphalt mixtures used to evaluate the mixtures during the laboratory design phase. Test results are compared against a set of minimum values that have been chosen to correspond with properties of mixes which have performed satisfactorily in the field. The Marshall values in the Florida Standard Specifications (*4*) have been verified from field performance in Florida. These specification values will need to be reviewed for HMA using asphalt-rubber binder combinations. The purpose of this section of the report is to relay the experience of previous research efforts relative to the effect of adding granulated scrap tire rubber to HMA mixtures.

Rubber-modified HMA. In Reference *30*, the authors stated that the standard Marshall samples were tested for flow and stability but that only air void content was used for design of the mixture. This clearly indicates, based on the experience of these engineers, that the relationship between field performance and Marshall stability and flow did not exist for these rubber-modified HMA mixes. The Marshall data developed in Reference *30* is shown in Table 18 for both the rubber modified and control mixes. Notice that the Marshall stability values are much lower for the rubber-modified mixes than for the control ranging from 29 to 61% of the control mix stability. The finer rubber gradation generally showed higher stability than the coarser rubber gradation. In addition, the Marshall flow values for the rubber-modified mixes are much greater than for the control ranging from 1.9 to 4.2 times the control mix flow with the finer rubber gradation showing the lower flow values.

Table 18. Marshall Mix Properties for Rubber Modified and Control HMA Mixes at 2% Air Voids (*30*)

Aggregate Gradation	Rubber Content	Rubber Gradation (% Coarse/% Fine)	Design Asphalt Content %	Marshall Stability lbs.	Flow (.01 in.)
Gap-Graded	2	0/100	7.0	920	15
		60/40	7.2	690	21
		80/20	8.0	665	23
	3	0/100	7.5	600	19
		60/40	7.5	650	22
		80/20	9.3	436	33
Dense-Graded	0	No Rubber	5.5	1500	8
	3	80/20	7.5	550	22

The same general trend toward reduced Marshall stability was also shown by Piggott and Woodhams (*33*) for the rubber modified HMA as compared to the standard HMA, Figure 21.

They, however, made a special note that these pavements had given good performance indicating that the rubber-modified mixtures do not conform to normal expectations on the basis of Marshall stability measurements.

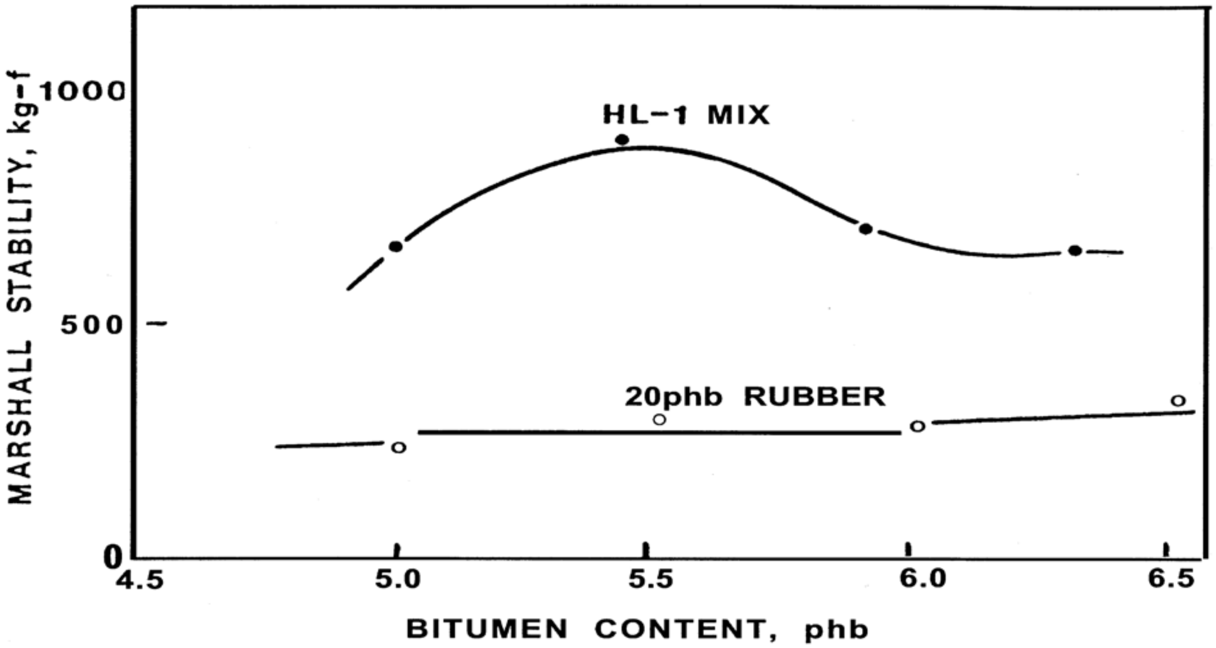

Figure 21. Marshall Stability for the Control (HL-1) Mix and the Rubber Modified Mix (2% Rubber in Asphalt) (33)

These data indicate that there is a need to evaluate the implications of Marshall stability and flow on the performance of rubber-modified mixes and perhaps use those test values only for selection of the optimum binder content but not as an indicator of acceptable field performance. Once sufficient field data has been collected to define the relationship between Marshall stability and flow and acceptable field performance, appropriate specification minimum levels and ranges can be confirmed. As a conservative beginning point, mixes using asphalt-rubber binders should meet the same Marshall stability requirements as conventional mixes. However, consideration should be given to increasing the marshall flow values, as described previously.

Asphalt-Rubber HMA. In References 31 and 32, asphalt-rubber was used as a binder in preparation of an asphalt hot mix material for airport runway application. In that study involving a dense graded aggregate meeting FAA specifications, the Marshall mix design properties of the asphalt-rubber concrete were very similar to those for the standard HMA mixture. Figure 22 shows plots of the Marshall property data for this mixture. Notice that the Marshall stability peaks at a low ‘binder content that corresponds to a 9% air void content. If a 4% air void criteria were applied to this mixture, then the stability would be much lower, the flow would be much higher, and the binder content would probably increase by at least 1.5%. Nevertheless, this material was predicted to perform quite adequately in the computer analysis discussed earlier in this chapter.

Another asphalt-rubber HMA design for a second limestone mixture was included in Reference 32 which showed that both stability and flow values would be in the acceptable range for HMA mixtures at an air void content of 4% (Figure 23). Since both these mixtures reported in References 31 and 32 are dense graded, it is quite possible that for gap graded and open graded mixtures the stabilities may be lower and the flows higher than allowable for standard HMA mixes.

Perhaps one way to avoid the concern of low stability for these mixes being recommended to the FDOT would be to have each contractor design the basic mixtures as a standard HMA insuring that all the Marshall mix criteria are met. Then, the FDOT State Materials Office could prepare the asphalt-rubber binder and check the preliminary design submitted by the contractor using the asphalt-rubber binder. If changes in binder content were necessary, those could be made and verified by FDOT personnel before construction.

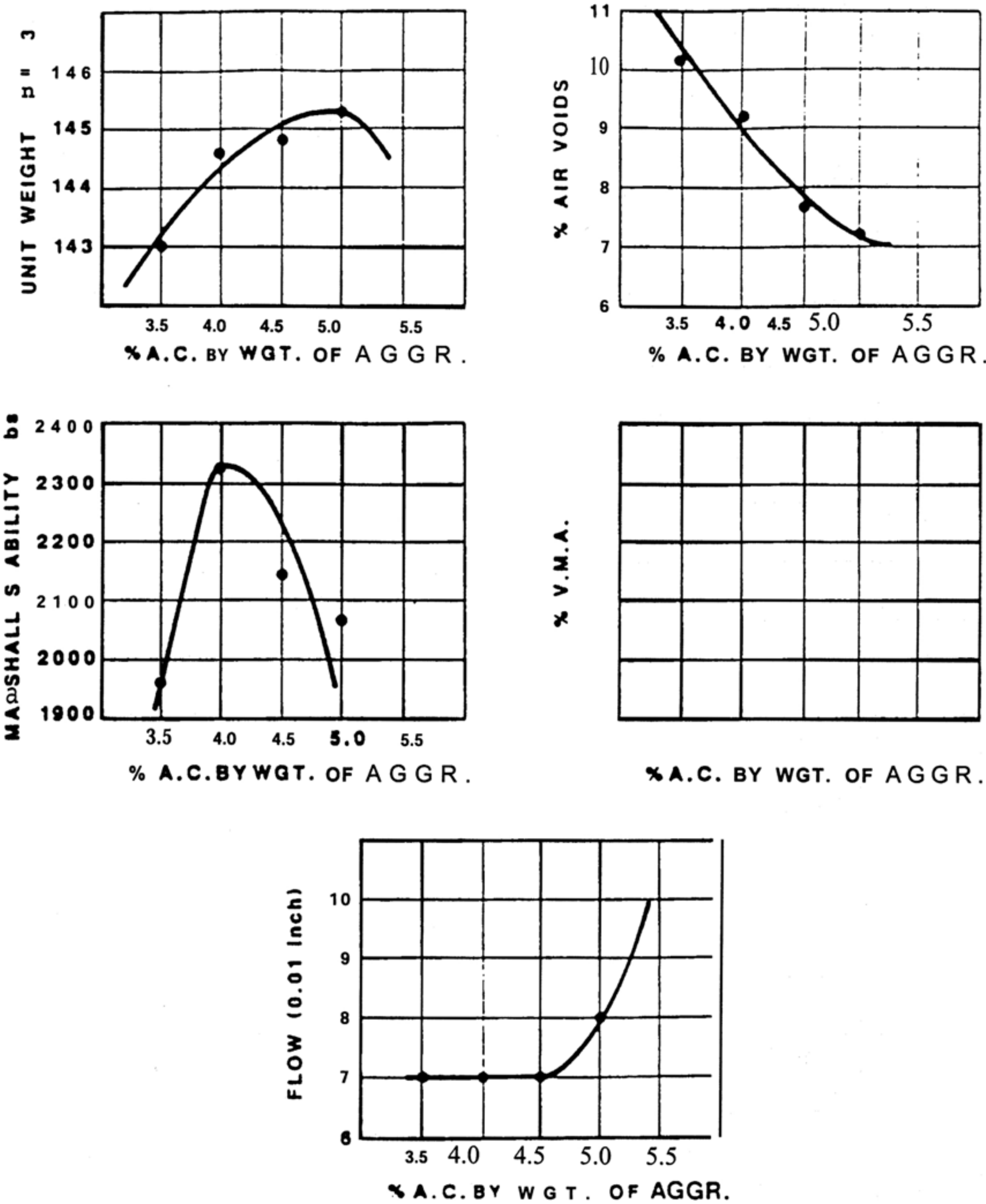

Figure 22. Marshall Test Data for an Asphalt-Rubber Concrete (31) (Prepared from Limestone Aggregate)

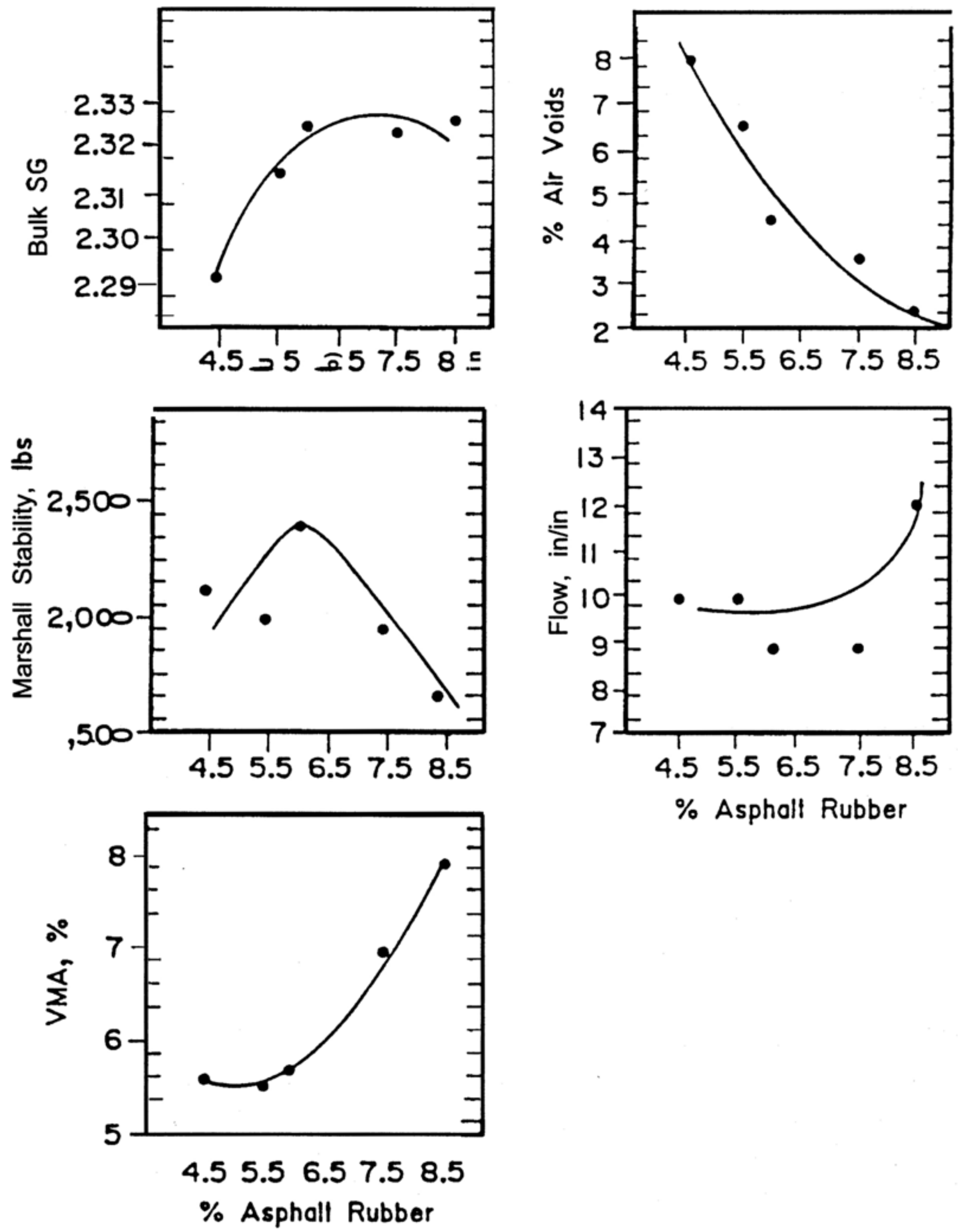

Figure 23. Marshall Test Data for an Asphalt-Rubber Concrete (*32*)
(Prepared from Limestone Aggregates)

Other Performance Considerations

Piggott and Woodhams (*33*) indicate that there maybe additional performance benefits which could accrue to a HMA as a result of incorporating ground tire rubber in the mix. The benefits cited in Reference *33* are stated below:

1. Improved low temperature flexibility exhibited by increased elongation that allows the pavement to yield without fracturing,
2. Improved strength retention when wet that may result from the effects of rubber additives (sulfur accelerators and zinc compounds) which may promote better adhesion with the aggregate through slow migration of surface active components to the interface,
3. Better resistance to flow or creep at elevated temperatures, and
4. Greater resistance to oxidative hardening due to the presence of rubber antioxidants.

CHAPTER 5. RECYCLING ISSUES

Task 4 has been divided into two subtasks. Subtask k deals with the effect of the use of recycling agents containing ground tire rubber on the recycled material, and the efficiency of the recycling process in rejuvenating the aged asphalt and providing a uniform distribution of material. Subtask 1 is more concerned with the re-recyclability, and the tests and specifications which will have to be developed. Task 4 is very important because FDOT is heavily involved in recycling asphalt pavements which has not only resulted in substantial economic benefits but has also conserved material resources. This recycling program should not be jeopardized in anyway merely to dispose of tires. Solution of one solid waste problem (tires) should not result in the creation of another solid waste problem (disposing of the RAP with rubber that cannot be recycled).

Subtask 4(k)

Identify and verify anticipated problems of using ground tire rubber with a recycling agent and its effect on the ability of the modified reqcling agent to rejuvenate the existing asphalt cement in the reclaimed asphalt pavement (RAP) and to provide a uniform distribution.

This subtask may be broken down into two work elements:

1. Identify and verify anticipated problems of using ground tire rubber with a recycling agent including its effect on the ability of the recycling agent to rejuvenate the reclaimed asphalt pavement (RAP).
2. Evaluate whether the rubber particles will become well distributed among all of the HMA in the recycled mixtures in which initially only part of the RAP would have contained rubber particles.

Background (Effect of Rubber on Asphalt Properties)

Before attempting to address the above issues, it would be well to discuss how rubber affects the behavior of asphalt. Decker et al (*19*) have reported that results of an extensive testing program involving 1250 individual laboratory tests representing 16 field rubber-asphalt combinations showed that the rubber may benefit the asphalt in the following ways:

- 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 (*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 (*35*) reported that vulcanized rubber is insoluble in asphalt. In the same reference, Rostler (*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 (*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 (*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 (*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 (*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. (*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 (*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 4(l)

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?" (*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 (*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 1(b). 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 2(g).

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 l(b) 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 5(h)

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¢/lb as compared to 14¢/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 (*31*, *47*). These data represent the cost to produce a rubber-modified HMA (*47*) and an asphalt-rubber HMA (*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

Table 19. Cost Comparison for Conventional and Asphalt-Rubber HMA Materials in the Continental USA (31)

	Asphalt Cement Binder		Asphalt-Rubber Cement Binder					
			Low Asphalt Rubber Content		Medium Asphalt Rubber Content		High Asphalt Rubber Content	
Component	$/Ton	Percent	$/Ton	Percent	$/Ton	Percent	$/Ton	Percent
Binder*	8.40	25.0	18.61	40.7	20.81	43.1	23.01	45.2
Aggregate	8.85	26.4	8.85	19.4	8.85	18.3	8.85	17.4
Energy Costs	1.20	3.6	1.28	2.8	1.28	2.7	1.28	2.5
Mixing	3.51	10.5	3.51	7.7	3.51	7.3	3.51	6.9
Haul, Laydown, and Compaction	5.92	17.6	5.92	13.0	5.92	12.3	5.92	11.6
Miscellaneous	0.66	2.0	0.66	1.4	0.66	1.4	0.66	1.3
Mark-Up (15%)	5.04	15.0	6.85	15.0	7.24	15.0	7.63	15.0
	33.58	100.0	45.68	100.00	48.27	100.00	50.86	100.00

* 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 (31)*

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

* 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/yd^2 or 4.5 lbs/yd^2.

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, 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.

<u>Estimated Cost Increase for FC-1 and FC4 Mixes</u>

- Typical FC-1 and FC-4 mixes contain 79% 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 = <u>1.25</u>
  $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%

<u>Estimated Cost Increase for FC-2 Mix</u>

- 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 = <u>1.25</u>
  $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 5(o)

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% 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 (<u>*48*</u>) and confirmed by Lee (<u>*49*</u>), and Kandhal and Wenger (<u>*50*</u>). 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:

$$AY = \frac{T}{a + bT} \qquad (1)$$

or $$\frac{T}{\Delta Y} = a + bT \qquad (2)$$

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
)Y = 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 (<u>*50*</u>) 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 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 (<u>*48*</u>).

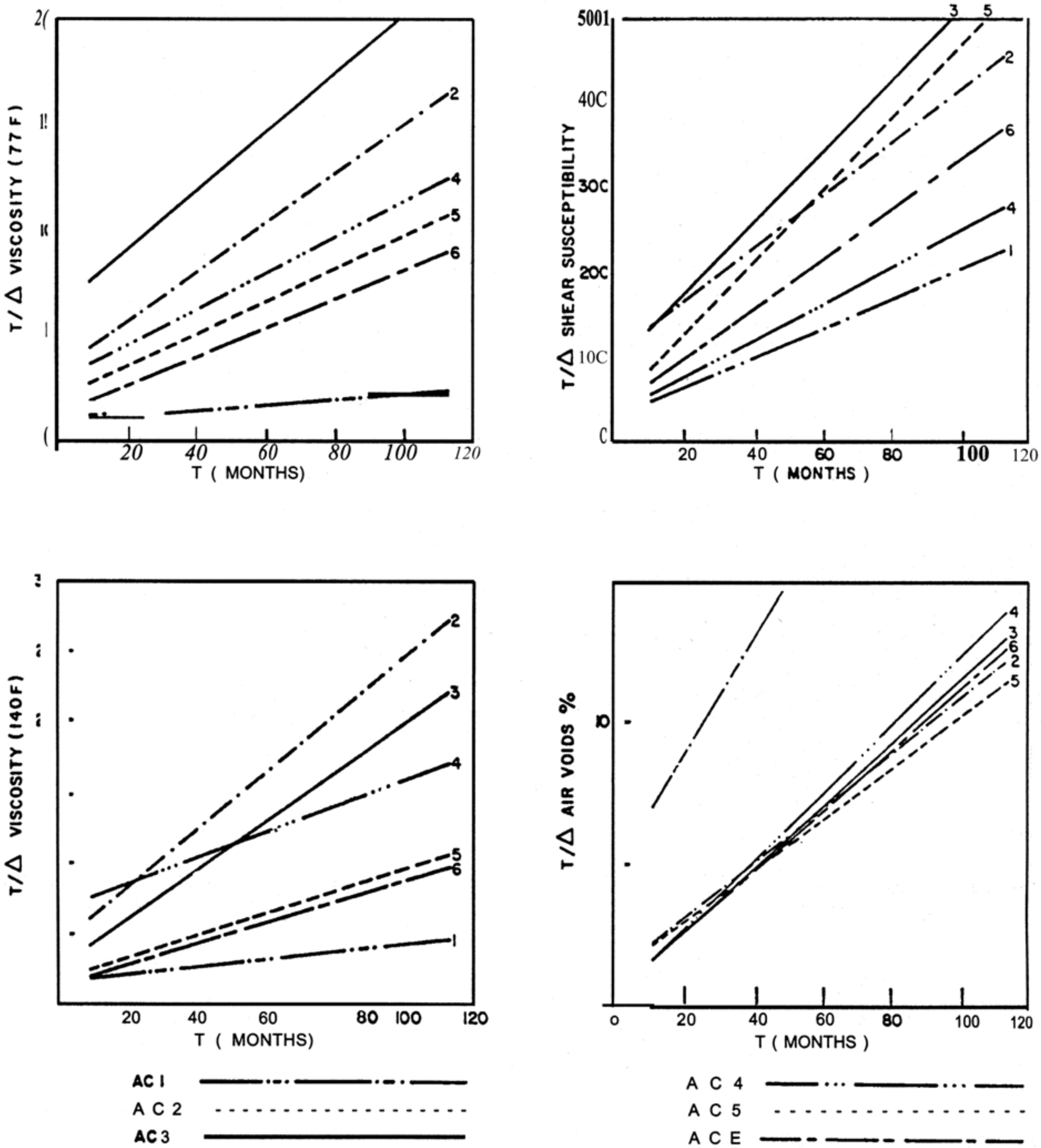

Figure 24. T versus T/A Plots (*50*)

Table 21. Linear Regression Data (T versus T/)Y) (*50*)

Test Property	Asphalt Type					
Y	1	2	3	4	5	6
Viscosity at 77°F						
r	0.970	0.950	0.834	0.987	0.968	0.950
a	0.495	3.233	5.965	2.740	1.717	0.961
b	0.017	0.116	0.141	0.086	0.081	0.071
Viscosity at 140°F						
r	0.975	0.941	0.974	0.935	0.982	0.961
a	1.531	4.144	2.756	3.447	1.399	1.834
b	0.029	0.207	0.122	0.118	0.081	1.071
Shear Susceptibility						
r	0.991	0.929	0.998	0.998	0.993	0.999
a	27.523	104.914	86.351	34.407	45.151	42.243
b	1.740	2.993	4.225	2.197	4.171	2.890
Percent Air Voids						
r	0.982	0.998	0.999	0.999	0.999	0.999
a	5.155	1.178	0.328	0.389	1.080	0.599
b	0.207	0.099	0.117	0.123	0.095	0.111

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 O, 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 5(p)

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 embedded 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 embedment.

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 a 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 wild life.

Subtask 5(a)

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 (*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 BTUs 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[1], located in Santa Rosa, California collects and

[1] Oxford Energy Company, 3510 Unical Place, Santa Rosa, CA 95403. (707) 575-3939. Contact: Robert D. Colman, President.

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 technolog 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.

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 maybe 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 (*52*).

Energy Products of Idaho[2] 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 (*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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[2] Energy Products, 4006 Industrial Ave. Coeur d'Alene, ID 83814. (208)765-1611. Contact: Kent Pope.

Tires as a Raw Material

Another approach to the disposal of scrap tires is that used in Babbitt, Minnesota, which is near Minneapolis (*54*). This county owned facility (Saint Louis County) is operated by Minneapolis-based Rubber Research Elastomers, Inc.[3] 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 (*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 TPRs.”

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.

[3] Rubber Research Elastomers, Inc., 4500 Main Street, NE, Minneapolis, MN 55421. (612) 572-1056. Contact: F. John Stark III.

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-l, 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 HMAs, the Marshall flow will increase, stability will likely decrease, the VMA wiIl 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 1(j).

   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 5(o), 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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- Subtask 1(f): Changes in mix design specifications and procedures.
- Subtask 1(d): Laboratory method of incorporating rubber into asphalt.
- Subtask 1(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 1(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 FDOT's extraction test method.

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APPENDIX A

Rubber Types

Introduction

While it is convenient to talk of tire rubber as if it is only one homogeneous material there are, in fact, several variations which affect the response and the reaction to various manufacturing processes. The two main types of compounded rubber in a tire are carcass compounds and tread compounds. The carcass stock will be less stiff than that used for the tread, and contain less carbon black. Another variation that is encountered in tires is the amount of oil added to the compound. Generally an aromatic oil, similar if not identical to those used for asphalt recycling, is added to the rubber as a processing aid. About 5% oil may be used for this purpose. Retread rubber may be compounded out of oil extended rubber which may contain over 50% oil per 100 parts rubber.

Another very important factor to consider with the evaluation of the use of tire rubber is the chemical composition of the rubber itself. Three major types of rubber may be used, often in blends; 1) polyisoprene, 2) polybutadiene, and 3) styrene-butadiene copolymers (SBR). The manner in which each of these rubbers behaves is different, although for the purpose of this discussion, the behavior of SBR and polybutadiene may be considered to be the same.

Polyisoprene

Although there is synthetic produced polyisoprene, natural rubber, which is 100% *cis*-polyisoprene, is generally the rubber that is used in tires, especially in truck tires, as natural *cis*-polyisoprene has excellent hot tear strength. (The term *cis* refers to the spatial configuration of the isoprene parts of the rubber chain. The other configuration is called *trans. Trans*-polyisoprene is a leathery material, rather than a rubbery one and is not used in tires.) Synthetic *cis*-polyisoprene generally has a cis content of less than 100%. As the *cis* content decreases, the ability of the rubber to form crystallite during extensions decreases. It is the formation of the crystallite which gives natural rubber its hot tear strength. In addition to the higher hot tear strength of natural rubber, *cis*-polyisoprene polymers, in general, have a lower hysteresis ener~ loss during flexure, thus tires made from them do not heat up as much as do tires made from SBR. Polybutadiene polymers also have a high resilience (low hysteresis energy loss), however they do not have the hot tear strength of natural rubber because of a considerable amount of trans and 1,2-moieties in the polymer chain which interfere with the crystallization of the *cis*-portions of the chain.

At high temperatures, especially in the presence of oxygen, polyisoprene polymer chains break. In the terms used in asphalt-rubber technology part of what is called “digestion” or reaction is a result of the reduction of molecular weight of the polyisoprene. This occurs not only in the presence of asphalt, but will occur in processing of rubber if the rubber is heated for a prolonged time, and undergoes high shear. If allowed to continue, the polymer can be reduced to a syrup. Since the viscosity building effect of rubber depends upon its molecular weight, the result is a continuing reduction of viscosity. This effect can be controlled, and very successful projects have been made with the tire buffings containing natural rubber. One positive aspect of this decline in molecular weight is that the lower molecular weight by-products add adhesion to the mixture, making the product more likely to stick to whatever it touches. Tight temperature and time control is needed, however, to assure uniformity of the product.

Polybutadiene and SBR

Polybutadiene polymers reduce the skid resistance of the tire, which results in it being used in blends with SBR. These blend are used for passenger tires, but not for truck tires because of the low hot tear strength.

Since polybutadiene acts much like SBR when it undergoes the processing in asphalt-rubber, we can really consider only tsvo types of behavior, that of polyisoprene containing polymers, and that of polybutadiene containing polymers.

Polymers made from butadiene, such as polybutadiene and SBR, respond in a different manner than polyisoprene polymers. Rather than breaking down, they tend to crosslink, or resinify. The "digestion" process is really not much more than swelling of the rubber, which increases in volume by about a factor of two, from the absorption of asphalt. The amount of swell and the resulting increase in viscosity is affected by the source of asphalt, with some asphalts causing more swell than others. Successful projects have been made with these systems also.

When digestion of these polymers is reported, as evidenced by a loss of weight of material from an extraction, it is most probable that the loss of weight is due to the extraction of processing and extending oils rather than a breakdown of a rubber containing the butadiene monomer.

Polybutylene

Polybutylene (butyl rubber) was used for a short time in tires, but as far as is known, is not being used at the present time. However, tubes for tires use this polymer because of its low air permeability.

Block Copolymers

The newer block copolymers have not at this time found much application to the tire industry since tires made from them tend to have poor abrasion resistance. We will not, therefore, comment on the differences in behavior should the tire be made out of those materials.

APPENDIX B

Quantitative Extraction of Rubberized Asphalt From Bituminous Paving Mixtures[4]

This test procedure for the extraction of the rubberized asphalt is similar to the current practice in the State of Florida (FM 1-T 164) with the exception that with the rubberized asphalt, the quantities of both the rubber and the bitumen in hot mix asphalt (HMA) pavement mixtures must be determined.

To determine the rubber content in the asphalt mixture, the asphalt cement must first be extracted by Rotorex extractor as in AASHTO T 164 method and FM 1-T 164.

The agent recommended for the extraction of the rubberized asphalt is 1,1,1 trichloroethane; conforming to Federal specification D-T-620. Trichloroethane technical grade, Type I. Federal specification O-T-634.

After the extraction of the asphalt cement by Rotorex extractor, the extraction of the rubber from the mixtures begins. Some rubber compounds may be dissolved by the 1,1,1 trichloroethane. In order to determine this quantity of rubber, five extraction tests should be run. The total material lost is either dissolved rubber or aggregate fines.

Five samples of hot mix asphalt without rubber should be extracted to determine the average loss of aggregate fines. The amount of rubber dissolved by 1,1,1 trichloroethane is the difference between the average loss of the five extractions with rubber and the average loss without rubber.

This rubber loss should be subtracted from the result of the extraction of the quantity of the bitumen in the HMA. This rubber loss should be determined for each construction project or for each change in the job mix formula.

To determine the rubber content remaining in the extracted aggregate, the following two methods are suggested:

METHOD A (Floating the rubber):

1. After determining the percent bitumen in the sample and making the necessary adjustment for the dissolved rubber, the rubber can be separated from the aggregate by the floating method.

2. Since the density of rubber is 1.19 grams/cm^3, a solution of the sodium bromide (NaBr) with a minimum density of 1.25 gram/cm^3 is sufficient to float rubber to the surface. Sodium bromide was selected because it has a relatively low cost and also is relatively safe and nontoxic.

3. Place the mixture of rubber and aggregate in large graduated cylinder or large bowl.

4. Add sufficient solution of sodium bromide (NaBr) having a minimum density of 1.25 grams/cm^3 to the mixture of aggregate and rubber to cover the mixture at least 2.5 inches.

5. Agitate and stir the solution and the mixture thoroughly for at least two minutes to allow all of the coarse and fine rubber particles to float to the surface.

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[4] Excerpted from a report by Dr. M.B. Takallou to NCAT

6. Allow the coarse and fine mineral aggregates to settle. A complete settlement can be achieved in 30 minutes.

7. Remove the rubber which is floating on the surface by skimming with a spoon or by using a dipper of sieve cloth with an opening of 0.075mm (No. 200).

8. Immediately pour the recovered rubber over a nested sieve consisting of a No. 200 sieve.

   NOTE: A sieve smaller than No. 200 will have to be used for 80 mesh rubber.

9. Wash the spoon or dipper over the No. 200 sieve.

10. Wash the sample over the No. 200 sieve with clean water to remove all of the sodium bromide.

11. Return all recovered rubber from the sieve to a container, being careful not to lose any rubber while transferring the rubber to the container.

12. Dry the washed sample to constant mass at 60/ & 5/C (140/ ~ 10”F) for six hours.

13. Weigh the dry rubber to the nearest 0.1 gram.

14. Calculate the percentage of rubber.

    Example:
    Mass of rubberized asphalt mixture = 1000gm
    Mass of rubber after drying six hours = 28 gm
    Assume 0.2% loss of dissolved rubber from the preceding calculation for the loss of rubber to trichloroethane.

    Thus:
    0.002 x 1000.0 = 2 gm.
    The % of rubber in the mix is ((28.0 + 2.0)/1000.0) *100 = 3.0%

METHOD B (Ashing the rubber):

1. After determining the percent bitumen in the sample and making the necessary adjustment for the dissolved rubber, the dry mixture of the rubber and aggregate will be subject to ashing.

2. Use a muffle furnace to ash the rubber in the sample. Only the material passing No. 4 (4.75mm) sieve portion of the extracted aggregate should be placed in the muffle furnace for four hours at 600°C.

   NOTE: The result of several experiments indicates that the rubber can be ashed almost 100% at a temperature of 600°C in the muffle furnace. 600°C is also the maximum safe temperature for heating aggregate without destroying the aggregate. It has been noted that some aggregate losses at this temperature could be due to the removal of absorbed water in the aggregates. The aggregate loss can be determined by heating a sample of aggregate without asphalt-rubber to determine this element of aggregate loss.

Example:

Mass of Mix	1000.0 g
Mass after bitumen extraction	930.0 g
Plus filter fines	12.0 g

Total mass in checking filter fines after extraction
930.0 + 12.0 g = 942.0 g
Those passing No. 4 (4.75 mm) sieve portion of the extracted aggregates were placed in the muffle furnace, for four hours at 600/C. Mass after four hours was 910.0 g.

485.0 g retained on 4.75mm sieve
423.0 g passing 4.75mm sieve
2.0 g filter residue
910.0

Therefore:
If aggregate loss due to heating is assumed to be 0.5% [(423 g x 0.005)=2.1 gm]
Total fine aggregate mass = 423 g + 2 g + 2.1 g = 427.1 g
The coarse aggregate (% retained on 4.75mm sieve) = 485.0 g
Total aggregate mass (Fine plus Coarse) = 485 g + 427.1 g = 912.1 g
The weight loss due to the rubber in the mixture =
930.0 g + 2.0 g -912.1 g = 19.9 g
If 0.2% of the rubber is assumed to be soluble in 1,1,1 trichloroethane
The loss of soluble rubber is (1000.0 g) (0.002) = 2.0 g

% of rubber in the mix is = $\frac{(19.9g + 2.0g)}{1000.0g} = \times 100 = 2.2\%$

APPENDIX C

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