NCAT Report No. 89-3

INVESTIGATION AND EVALUATION OF GROUND TIRE RUBBER IN HOT MIX ASPHALT

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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 curently 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 jepordize 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?6 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 percent.

(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.

Freddy L. Roberts
P.S. (Ken) Kandhal
E. Ray Brown
Robert L. Dunning
NCAT, August 1989

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.

Ambient ground rubber 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.

Cryogenically ground rubber 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 percent 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 the effect of rubber modified 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 interact ion 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 la.

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 (Ref. 1). Other chemical compositional differences between whole carcass and tread rubbers are of no major significance.

Rubber Type

In addition to automobile tires, truck and bus tires also pose a disposal problem. However, these tires represent less than 20% 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 (Ref. 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.

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 (Ref. 1) found rubber morphology

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

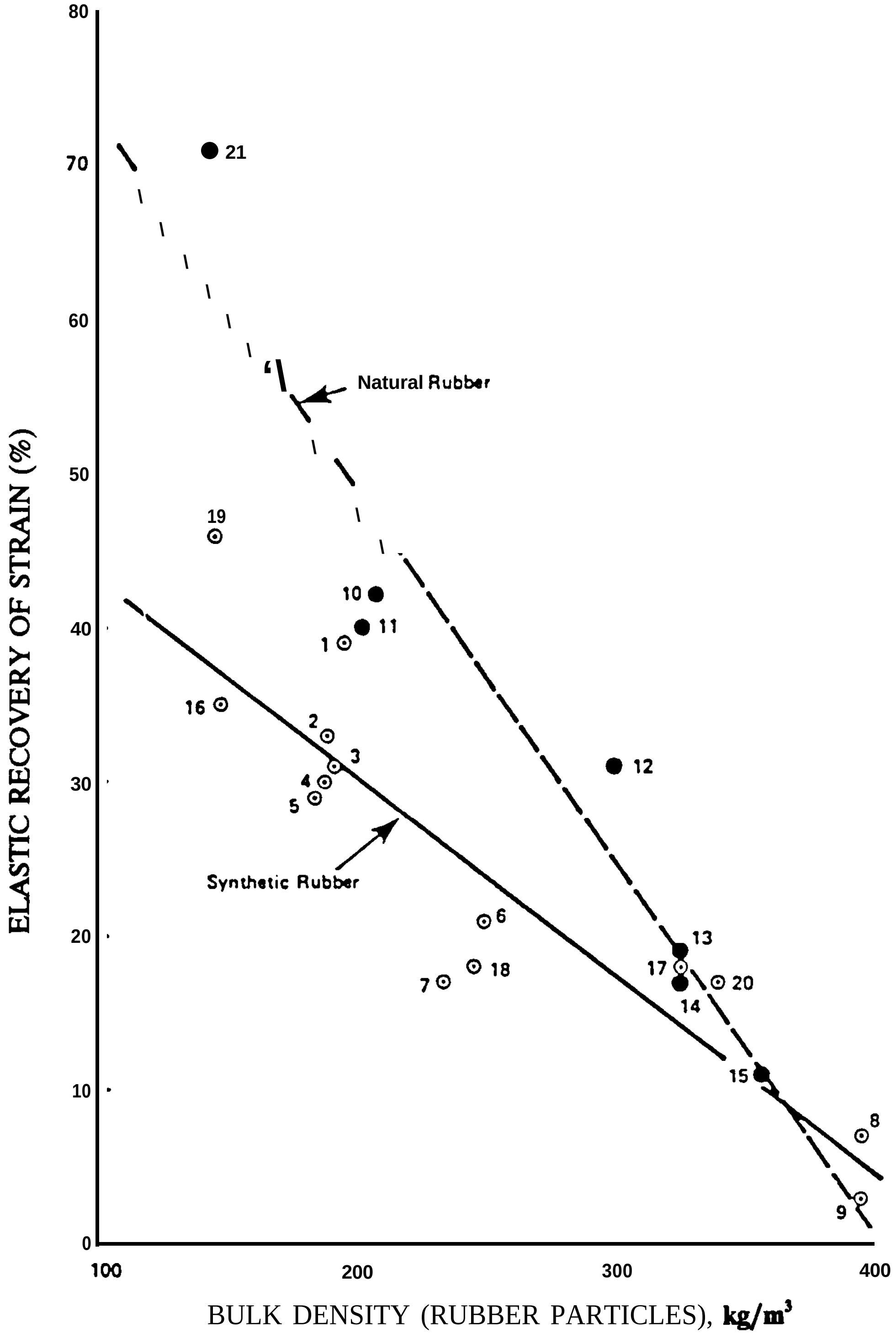

Figure 1. Relationship Between Elastic Recovery and Bulk Density (Ref. 2)

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

(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 (Ref. 1). The angular smooth-faced particles are produced using cryogenic grinding. Shuler (Ref. 3) reached similar conclusions. However, those results were confounded with particle size and natural rubber content differences. Oliver (Ref. 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 materials from its asphalt-rubber work by specifying a maximum bulk density of 350 kg/m^3 for 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 (Ref. 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.

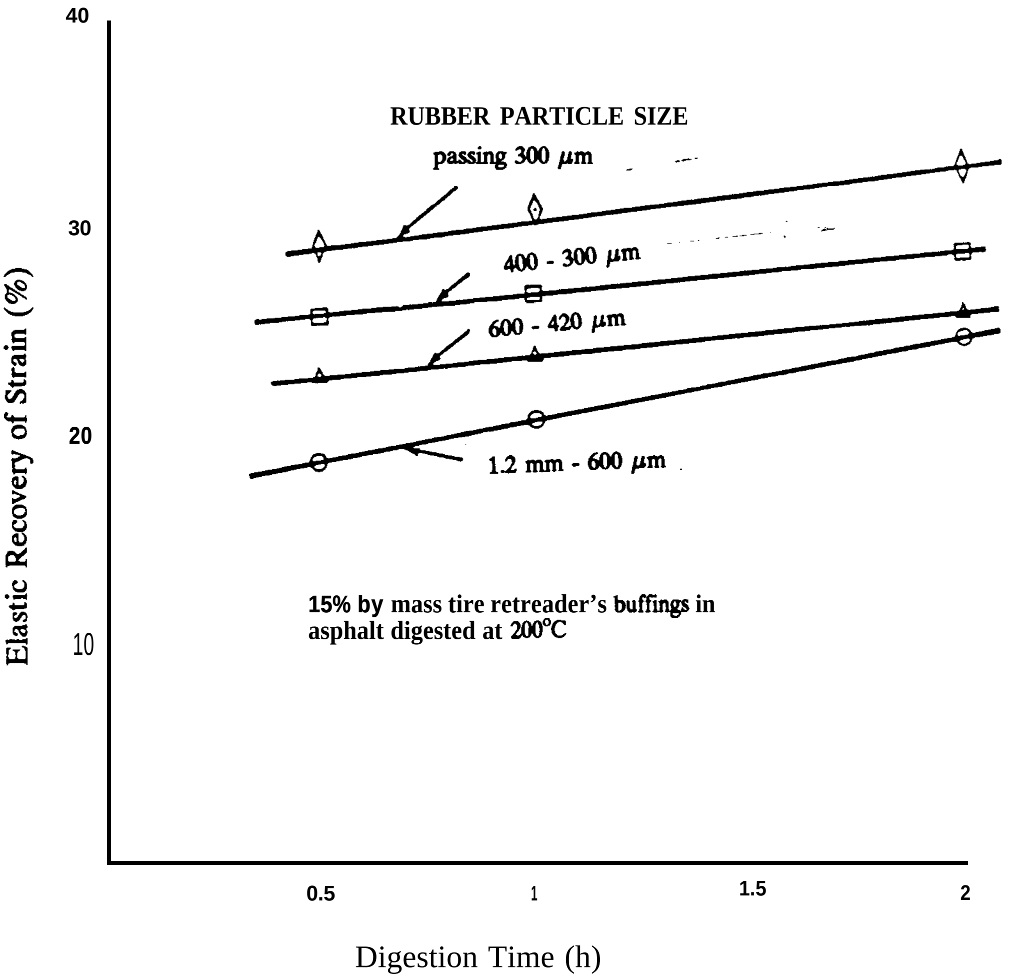

Figure 2. Effect of Particle Size on Elastic Recovery for Tire Retreader's Buffings (Ref. 2)

Shuler (Ref. 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% 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.

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 (Ref. 4) as well as the typical size distribution for recycled rubber products normally used in asphalt-rubber (Ref. 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,

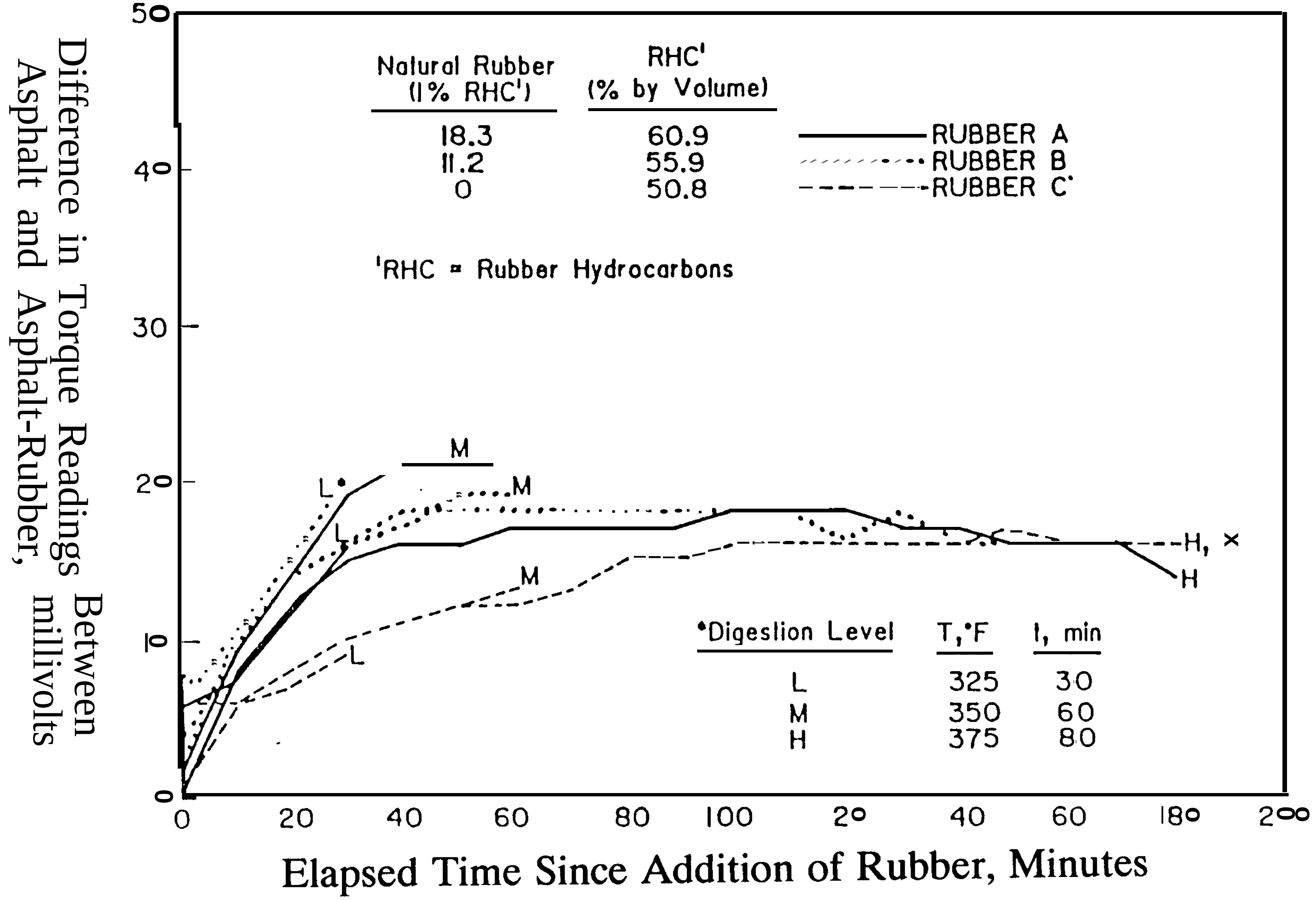

Figure 3. Torque Fork Output for Three Rubbers Used in El Paso at 22 percent Rubber and Three Digestion Levels (Ref. 3)

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

Seive	Florida Mixes			Recycled Rubber Type					
Size	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		--	--

reducing the size of the recycled rubber particles will increase the rubber processing cost.

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 lb.

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.

Discussion of the Laboratory Tests

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)

Table 4. Laboratory Tests used to Characterize Asphalt-Rubber

	Reference Number											
Laboratory Procedure	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 Pint (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					

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 (Ref. 6) termed the modified version “Phase Change Test”. Newcomb et al. (Ref. 7-9) 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 (Ref. 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. (Ref. 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. (Ref. 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. (Ref. 12) 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

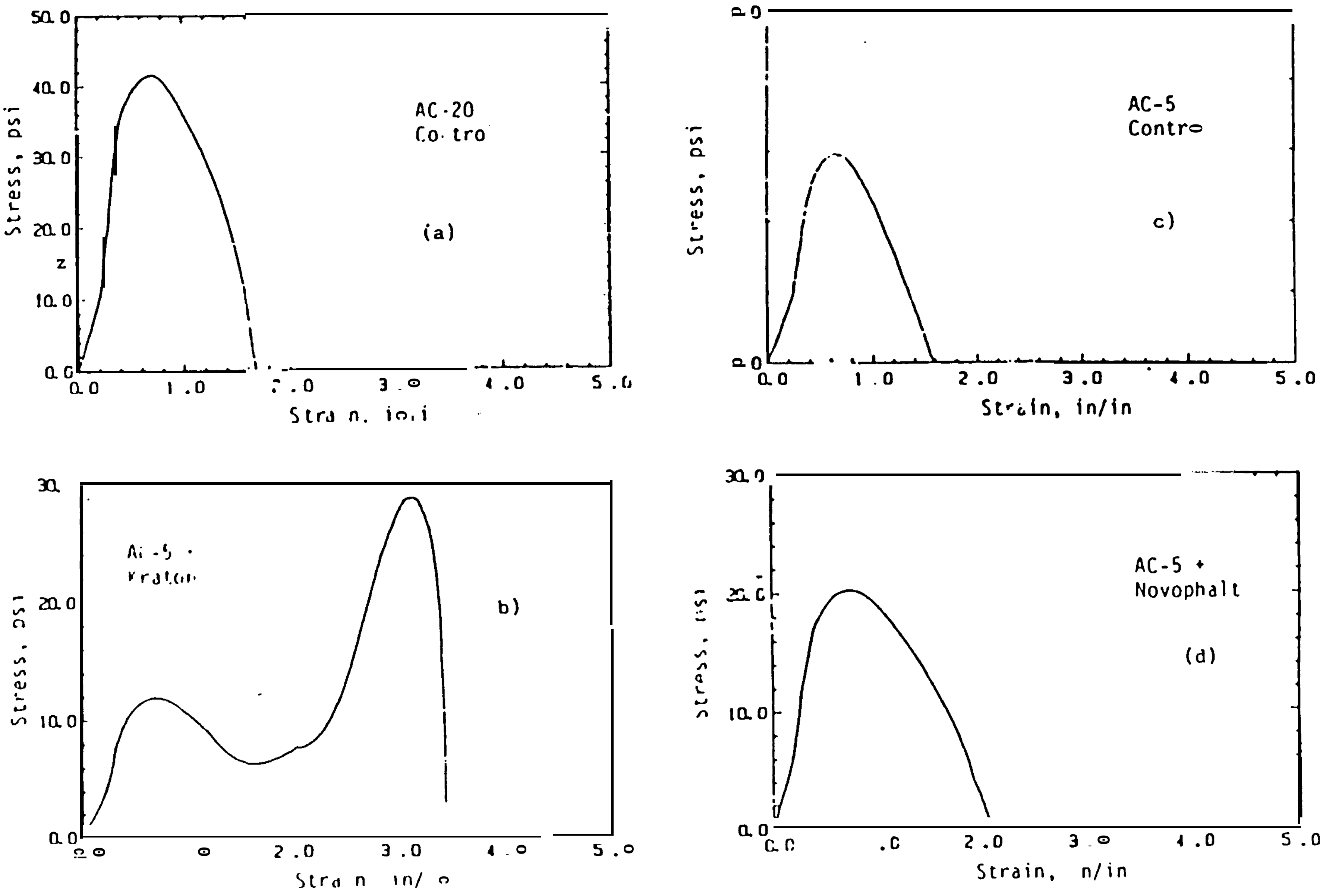

Figure 4. Typical Stress-Strain Curves from Force Ductility Tests at 30.2°F cm/min for Unmodified and Modified Texas Coastal Asphalts

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 (Ref. 13) 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.

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

Viscosity at Constant Shear Stress (Schweyer) Test

The viscosity at constant shear stress test was developed by Herbert Schweyer et al (Ref. 17) to test asphalt cements. Jimenez (Ref. 11) 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 9 and 11.

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 (Ref. 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 (Ref. 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 (Ref. 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 (Ref. 5). Toughness is defined as the work represented by the total area under the curve, and tenacity by the area

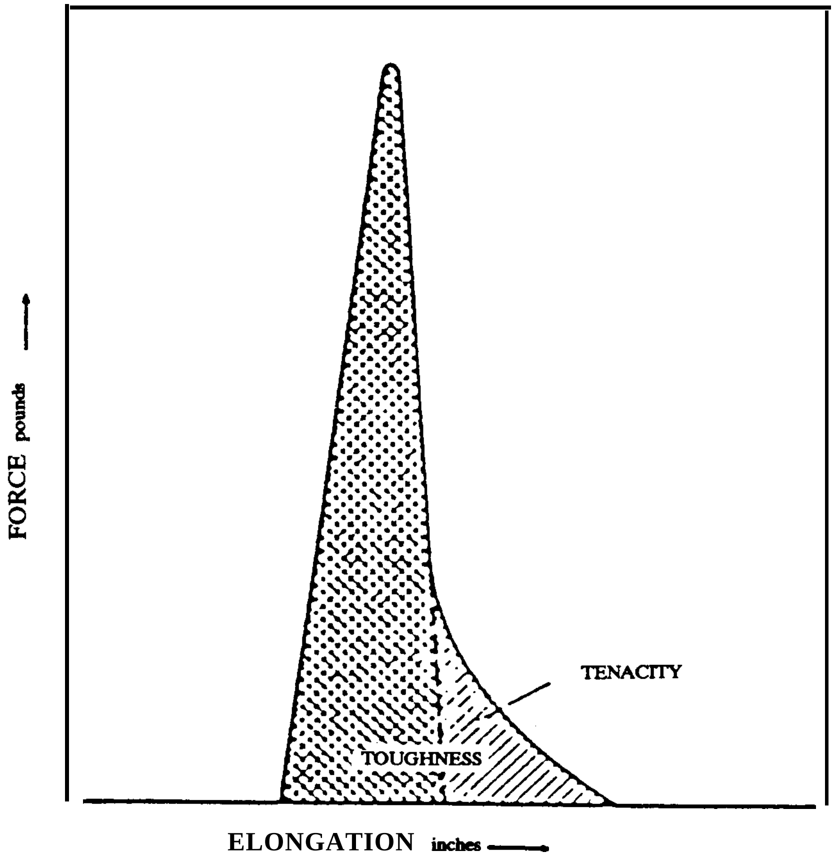

Figure 5. Force-Elongation Curve (Ref. 5)

bounded by the curve at high elongation and a projection of the curve directly from peak to the axis as shown in Figure 5.

Collins (Ref. 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 (Ref. 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 (Ref. 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

Table 5. Gradation of Rubber Particles for Rubber-Types in the Study (Ref. 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.

run in accordance with modified ASTM C136. The modification consists of (1) adding 1-2% 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.

Other Tests

Listed below are tests which are increasing in popularity in current research efforts. King et al (Ref. 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 t 1.

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 tl 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/t 1 provides an approximate relationship between the elasticity or tensile strength after elongation and the original viscosity.

King et al (Ref. 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 is time dependent, it is necessary to either monitor the elastic recovery per unit time or specify 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:

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

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