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Joint Highway Research Project

Interim Report

FHWA/IN/JHRP-92/11

Laboratory Study on Properties of Rubber Soils

Imtiaz Ahmed

PURDUE UNIVERSITY

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LABORATORY STUDY ON PROPERTIES OF RUBBER SOILS

by

Imtiaz Ahmed
Graduate Research Assistant

Joint Highway Research Project

Project No.: C-36-50L
File No.: 6-19-12

Prepared as Part of an Investigation
conducted by the
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Purdue University

In Cooperation with the
Indiana Department of Transportation
and the
U.S. Department of Transportation
Federal Highway Administration

Department of Civil Engineering
Purdue University
West Lafayette, Indiana 47907

May 1992

Interim Report
LABORATORY STUDY ON PROPERTIES OF RUBBER SOILS

To: Dr. Vincent Drnevich, Director
Joint Highway Research Project

May 18, 1992
Project No. C-36-50L
File No. 6-19-12

From: C. W. Lovell
Professor of Civil Engineering
Purdue University
West Lafayette, Indiana

Subj: Laboratory Study on Properties of Rubber Soils

Attached is the interim report on the subject study. The report has been prepared by Mr. Imtiaz Ahmed, Graduate Research Assistant, under my direction.

This report presents the literature review and results from the compaction phase of the ongoing laboratory study. The report contains: an overview of current practice in recycling, reuse, and disposal of waste tires; a comparison of various lightweight materials traditionally used in highway construction; a summary of the various field and laboratory studies on the use of shredded tires as lightweight fill; results and analysis of compaction testing of rubber soils; and the conclusions of this study. The findings of this study will help the INDOT to determine the feasibility of using waste tires in various highway applications, especially the use of shredded tires in embankments, and plan a course of action to share the nation's burden in solving the waste tire problem.

This report is submitted for acceptance in partial fulfillment of the referenced study.

Respectfully Submitted

Cw Lovell

C. W. Lovell

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16. Abstract

The waste tire problem in the United States is of great magnitude and has far reaching environmental and economic implications. This report presents the literature review and results from the compaction phase of an ongoing laboratory study. The report contains: an overview of current practice in recycling, reuse, and disposal of waste tires; a comparison of various lightweight materials traditionally used in highway construction; a summary of various field and laboratory studies on the use of shredded tires as lightweight fill; results and analysis of compaction testing of rubber soils; and a summary of conclusions.

The use of shredded tires in highway construction offers technical, economic, and environmental benefits under certain conditions. The salient benefits include: reduced weight of fill; serves as good drainage medium; reduced backfill pressures; longer life, tires are practically non-destructible; and recycling large quantities of tires. Potential problems include: leachate of metals and hydrocarbons; fire risk; and large compressibility of tire chips. Information concerning stress-strain-strength behavior of tire chips for design and performance prediction of tire embankments, and long term environmental impacts of shredded tires are severely lacking.

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Finally, I am grateful to my wife, Musarrat Imtiaz, for her continuous support and encouragement and my children for their patience during the course of this research.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway Officials
ASTM	American Society for Testing and Materials
CRA	Crumb Rubber Additive
Cu	Cubic
DOT	Department of Transportation
EPA	Environmental Protection Agency
Ft	Foot/Feet
HMA	Hot Mix Asphalt
DOT	Department of Transportation
INDOT	Indiana Department of Transportation
Mn/DOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
MSW	Municipal Solid Waste
RAL	Recommended Allowable Water Limits
SAM	Stress Absorbing Membrane
SAMI	Stress Absorbing Membrane Interlayer
TCT	Twin City Testing Corporation
USCS	Unified Soil Classification System
US	United States
Yd	Yard(s)

Note: The abbreviations used in the tables are described under each table

TECHNICAL SUMMARY

Indiana Department of Transportation Purdue University, School of Civil Engineering Joint Highway Research Project West Lafayette, IN 47907 Phone: (317) 494-2159	Laboratory Study on Properties of Rubber Soils FHWA/IN/JHRP-92/11 May 18, 1992 Interim Report

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Background

The waste tire problem in the United States is of great magnitude and has far reaching environmental and economic implications. The 1991 Indiana Legislature passed Senate Bill No. 209 and House Bill 1056 dealing with the potential use of waste materials in highways. These bills require the Indiana Department of Transportation (INDOT), in cooperation with state universities, to study the feasibility of using waste tires in road construction. This study is motivated by the INDOT's commitment to promote the use of waste products in highway construction and also to satisfy the requirements of Senate Bill No. 209 and House Bill 1056.

This report presents the literature review and results from the compaction phase of the ongoing laboratory study. The report contains: an overview of current practice in recycling , reuse, and disposal of waste tires; a comparison of various conventional lightweight materials; a summary of the various field and laboratory studies on the use of shredded tires as lightweight fill; results and analysis of compaction testing of rubber soils; and a summary of conclusions. In the subsequent phases of this study, stress-strain and strength behavior of compacted rubber soils will be determined. The economic and environmental aspects of this application of tires will also be analyzed.

Results

The various options available to reduce the tires disposal problem include: the reduction of waste tire generation; reuse of tires and its products; the reclaiming of constituent materials; and the recovery of heat value. Of the available options, no single option can significantly minimize the tire disposal problem, economically and also in environmentally acceptable manner. Many options need to be simultaneously tried and developed to solve the problem. Recycling of tires and its products is considered the most attractive option.

Shredded tires have been used as lightweight fill material in Colorado, Minnesota, North Carolina, Oregon, Vermont, Washington, and Wisconsin. Their use in highway construction offers technical, economic, and environmental benefits under certain conditions. The salient benefits are: lighter in weight, high elastic strength, practically non-destructible, highly permeable material, easy to compact, inexpensive, and use of large quantities of tires. Potential problems include: leachate of metals and hydrocarbons; fire risk; and large compressibility of tire chips. Information in following areas are severely lacking: stress-strain and strength behavior of chips and chip-soil mix for design and prediction of performance of highway structures; long term impact on environments; and potential economic benefits in the use of tire chips in INDOT facilities.

Conclusions

Tires are one of the most persistent waste disposal problems. A comprehensive strategy need to be developed and pursued to combat this problem at government, industry, and public levels. Technical, economic, and environmental concerns must be addressed prior to extensive use of shredded tires in the INDOT facilities. The ongoing laboratory study will provide useful information concerning various aspects of design and construction of tire embankment. A shredded tire test embankment may be planned to determine the long term environmental impacts of using shredded tires as lightweight fill material.

SECTION 1

INTRODUCTION

1.1 Background

Current estimates by the Environmental Protection Agency (EPA, 1991) indicate that over 242 million scrap tires are generated each year in the United States (see Table 1.1). In addition, about 2 billion waste tires have been accumulated in stockpiles or uncontrolled tire dumps across the country. The Indiana Department of Environmental Management has documented over 40 stockpiles, spread over 25 counties in Indiana, containing millions of tires (IDEM, 1991). It is estimated that approximately one tire per person is discarded each year, i.e., about five million waste tires are generated each year in Indiana. The current practice in scrap tire disposal indicates that of the 242 million tires discarded annually in the United States, 5% are exported, 6% recycled, 11% incinerated, and 78% are landfilled, stockpiled, or illegally dumped.

The composition of rubber tires makes them bulky, resilient, compaction resistant, and non-biodegradable. Disposal of large quantities of tires has accordingly many economic and environmental implications. Scrap tire piles which are growing each year pose two significant threats to the public: fire hazard - once set ablaze, they are almost impossible to extinguish; and health hazard

Table 1.1: SCRAP TIRE GENERATION IN THE UNITED STATES (AFTER EPA, 1991)

(in thousands)

	Year						
Replacement Tire Shipments	1984	1985	1986	1987	1988	1989	1990
Passenger [1]	144,580	141,455	144,267	151,892	155,294	151,156	152,251
Truck[1]	31,707	32,098	32,392	34,514	33,918	35,172	36,588
Farm Equipment[1]	2,592	2,395	2,319	2,658	2,662	2,664	2,549
Imported Used Tires[2]	1,793	3,233	2,552	2,925	1,352	1,466	1,108
Total Replacement Tires	180,672	179,181	181,530	191,989	193,226	190,458	192,496
Tires from Scrapped Vehicles[3]							
Cars	26,700	30,916	33,768	32,412	35,016	37,200[4]	39,000[4]
Trucks	6,408	8,400	9,236	9,456	9,004	10,400[4]	11,000[4]
Total Tires from Scrapped Vehicles	33,108	39,316	43,004	41,868	44,020	47,600	50,000
Total Scrap Tires in USA	213,780	218,497	224,534	233,857	237,246	238,058	242,496
US Population (thousands)[3]	235,961	238,207	240,523	242,825	245,807	247,732	249,981
Scrap Tires/Person/Year	0.91	0.92	0.93	0.96	0.97	0.96	0.97

Notes:

[1] (includes imported new tiers) National Petroleum News, Fact Book, 1986-1988. Data from the Rubber Manufacturers Association. 1988 through 1990 data from RMA Industry Monthly Tire Report, December 1989 and December 1990.

[2] U.S. Department of Commerce. "U.S. Imports for Consumption." (FT246). 1984-1990

[3] U.S. Department of Commerce, Statistical Abstracts, 1990 and prior years. Estimate based on 4 tires per vehicle.

[4] Estimated by Franklin Association, by linear extrapolation.

- the water held by the tires attracts disease-carrying mosquitoes and rodents. Efforts to sharply reduce the environmentally and economically costly practice of landfilling/stockpiling have stimulated the pursuit of non-landfill disposal or reuse of waste tires.

The composition of rubber tires, i.e., integrally combined rubber, synthetic fibers, steel, etc., has made it difficult to separate into ingredients for reuse and has led to unique problems for disposal of tires. However, it has also rendered some useful mechanical properties to this waste product, which has made recycling of tires economically beneficial. Tires are elastic, lightweight, durable, and yield high BTU when incinerated. In addition, recycling of tires has a positive impact on environments. In view of potential economic and environmental benefits associated with the reuse/recycling of waste tires, the use of this product is being experimentally studied for a variety of applications.

Figure 1.1 schematically show the waste tire generation cycle. From the manufacturer, tires are brought into use through an extensive distribution network to tire dealers. When the initial tread is worn down to the minimum acceptable standard, or when sidewall carcass damage prevents the tire being used safely, the tire enters the inventory of used tires. These tires may be sent to landfills, incinerators, or be chosen as suitable for retreading. The used tires may be sent to tire processing

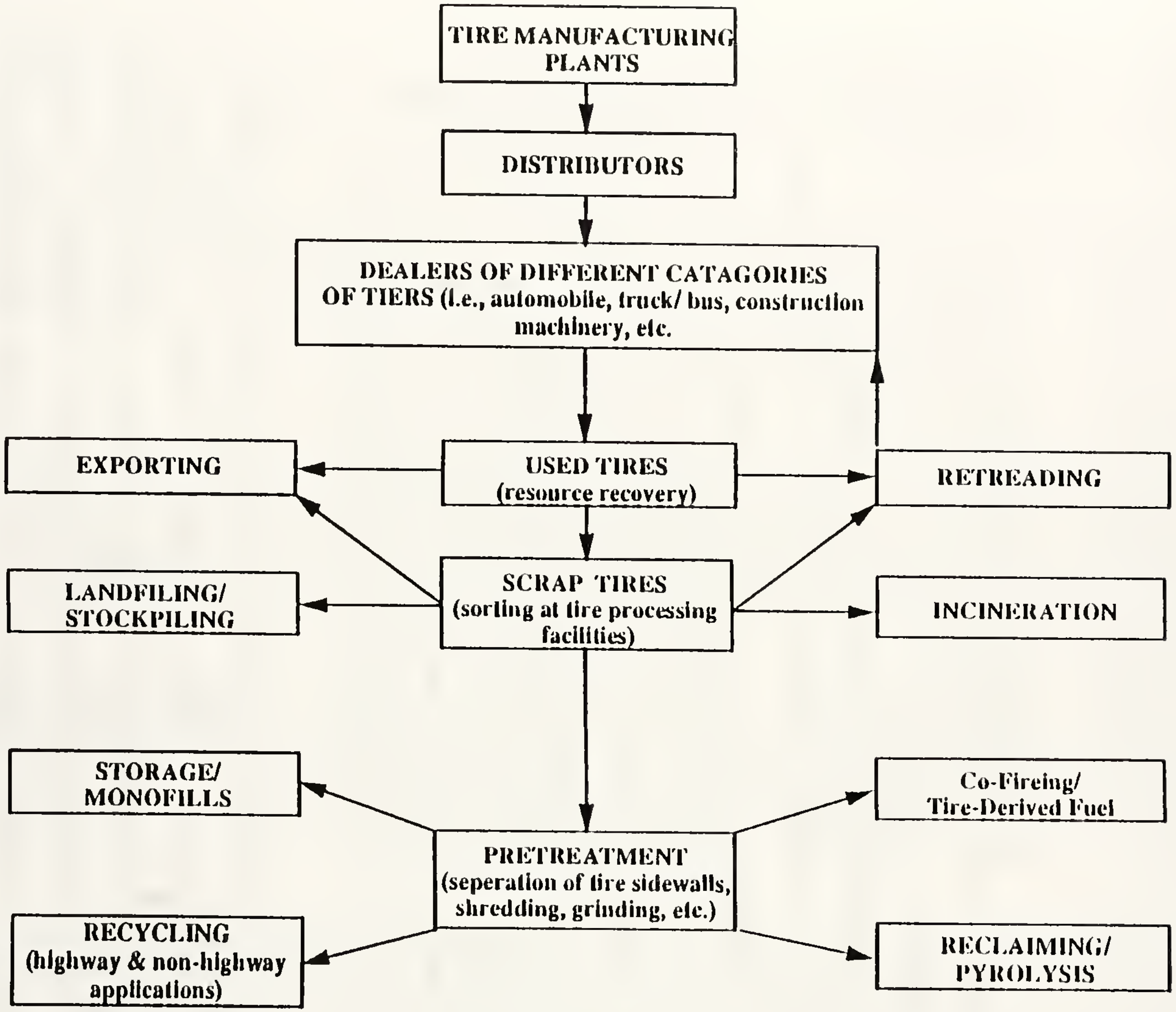

Figure 1.1: Tire Manufacturing, Retreading, and Discards

facilities where they are sorted, and those found unsuitable for retreading or exporting may be reduced to smaller size chips through shredding, ground to crumb rubber, or their ingredients may be separated through pyrolysis for reuse in manufacturing plants. The whole tires, shredded tire chips, crumb rubber, and materials reclaimed through decomposition of tires may be used for a variety of engineering applications, which are discussed in Section 2 of this report.

Recently, the author conducted a synthesis study (Ahmed, 1991) to identify those waste materials which have demonstrated technical, economic, and environmental feasibility for use in highway construction. The questionnaire survey conducted as part of this study indicated that of the 44 state highway agencies responding to the questionnaire, 30 states are currently using or experimenting with the use of rubber tires in a number of highway applications. The study concluded that the shredded tires indicate significant potential for use in highway construction as a lightweight fill or as a soil reinforcement material. However, it was found that further research would be required in certain areas prior to extensive use of tire chips in highway embankments.

Various highway agencies, in the United States (e.g., Colorado, Minnesota, North Carolina, Oregon, Vermont, Washington, and Wisconsin) and abroad, have practiced and evaluated the use of shredded tires as a lightweight fill material. Their experience indicated that the use of shredded tires in embankments is feasible and quite beneficial (see Section 3). In addition, inclusion of tire chips, which possess high tensile strength, in embankment fill is likely to increase the shear strength of soil. The use of shredded tires as a lightweight fill or as a soil reinforcement material seems promising. However, information on this application of waste tires is severely lacking. Only a few limited laboratory studies have been reported in the literature.

The 1991 Indiana Legislature passed Senate Bill No. 209 and House Bill 1056 dealing with the potential use of waste materials in road construction. Portions of those bills relate to waste tires. The bills require the Indiana Department of Transportation (INDOT), in cooperation with state universities, to study the feasibility of using waste tires in road construction. They require the INDOT to: (1) report the department's findings to the legislative council, the governor, and the general assembly before July 1, 1992; and (2) develop necessary changes in specifications and procedures as warranted by research findings. The copies of Senate and House bills are included in Appendix A and B, respectively.

The INDOT has been using recycled or waste products for many years in those applications which have been proven effective. They have also researched the use of a variety of waste products in highway construction to find an alternative source of material supply to offset the rising cost of quality natural aggregates, waste disposal, and energy (see Ahmed (1991) for the INDOT's experience in the use of waste products). This study is part of the INDOT's commitment to promote the use of waste product in highway construction and also to satisfy the requirements of Senate Bill No. 209 and House Bill 1056.

1.2 Objectives

The principal objectives of this study are to:

- determine stress-stain-strength characteristics of compacted rubber soil samples;
- analyze results of studies on leachates from waste tires to determine environmental acceptability of using shredded tires in highway embankments;
- evaluate economic benefits to the INDOT in using shredded tires in place of conventional materials in highway embankment construction; and
- define screening procedures, testing standards, and specifications for use of shredded tires in embankments.

1.3 Research Approach

The tasks necessary to accomplish the stated objectives include:

(1) Review of all available information on: the use of

shredded tires in highway embankment; and current state of generation, disposal, and shredding of waste tires in Indiana.

(2) Formulation of sampling criteria, based on the information obtained in Item (1), and collection/ procurement of tire chips/soils for testing.

(3) Acquisition, modification, and/or manufacture of testing equipment.

(4) Compaction tests to determine appropriate mold size, compactive effort, and optimum water content for various tire chip/soil ratios.

(5) Determination of stress-strain-strength properties of compacted rubber-soil samples through triaxial compression tests.

(6) Evaluation of compressibility of compacted rubber-soil samples under dynamic loading;

(7) Analysis of results from studies on leachates from rubber tires.

(8) Economic analysis based on the available data on the relative availability and costs of shredded tires versus conventional highway materials used in embankment construction.

(9) Analysis of data obtained from laboratory testing.

(10) Preparation of report containing recommendations to the INDOT, which will form basis for the development of bid specifications by the INDOT.

This study is planned to be completed within a period of two years, with a draft final report submitted to the INDOT by July 1, 1993. This report contains information on research study completed until April 1, 1992. The information has been obtained through an extensive literature review and laboratory testing of rubber-soils specimens. Published material has been the main source of information. However, in certain cases, material from some unpublished state highway agency reports and research updates is also included to benefit from the findings of recent research studies.

The laboratory study, reported in the subsequent sections of this report, include: selection of test soils and rubber chips, determination of index properties of testing materials, and compaction testing of rubber soil mixes. The author will continue the review and synthesis of information reported in the literature and the laboratory testing of rubber-soils specimens to accomplish the above stated objectives. The test data and results obtained during further research on the use of shredded tires in highway construction and the final analysis, conclusions, and recommendations will be published in the final report, due before July 1, 1993.

This report contains synthesis of information on various topics related to the use of rubber soils in highways and the available results from the ongoing experimental study. The report is structured as follows: Section 2 gives an overview of current practice in recycling, reuse, and disposal alternatives for scrap tires. Sections 3 discusses the use of shredded tires as a lightweight geomaterial. Section 4 describes the tire chips, test soils, testing equipment and experimental procedures. An outline of the testing program is also included in the section. Section 4 also presents and analyzes the results from compaction of rubber soils mixes. Finally, Section 5 summarizes the main conclusions of the ongoing experimental study, and provides recommendations to the INDOT. Section 6 gives a list of references.

SECTION 2

CURRENT PRACTICE IN RECYCLING, REUSE, AND DISPOSAL OF SCRAP TIRES

2.1 Introduction

Efforts to utilize scrap vulcanized rubber dates back to 1858 when Hiram Hall developed the heater pan process for reclaiming natural rubber vulcanizates. The reclaimed product was extensively used, since the reclaiming process was relatively simple and economical (Beckman, et al., 1974). However, as the rubber industry developed synthetic elastomers and the tire industry initiated the use of glass and steel for reinforcement, the reclaiming of scrap tires became progressively more difficult and expensive. The technical advances in tire manufacture have provided a product which is practically indestructible and also difficult to separate into ingredients. These are the leading causes of current tire disposal problems.

Several options are available to solve or minimize the tire disposal problem, including: source reduction by producing longer wearing tires, retreading and reuse of scrap tires; incineration of tires with generation of energy; recycling of whole tires for construction of various products; and processing the tires for use in a variety of applications. Some of these options have been investigated over the years within the United States and abroad. The following subsection gives an overview of current practice in the United States in the use of scrap tires in highway construction. The various options available for the reuse, disposal, and recycling of scrap tires are then described in some detail in the subsequent subsections. Finally, this section also gives a brief discussion on the various uses of waste tires and a summary of conclusions.

2.2 An Overview of Current Practice in the Use of Rubber Tires in Highway Construction

The technology for the use of rubber tires in a variety of highway applications is being developed for the past many years. The whole tires have been used, with some success, for soil retaining, erosion control, and construction of sound/crash barriers. The highway industry has also investigated the use of three products reclaimed from scrap tires, which include crumb rubber, shredded tires, and tire sidewalls. Addition of crumb rubber in asphalt produces a binder with improved mechanical properties. This binder (called asphalt-rubber) is used in asphalt paving products, including crack/joint sealant, surface/interlayer treatments, wearing courses, etc. In addition, crumb rubber is also added to specially graded aggregates to produce rubber modified asphalt mixtures. Shredded tires are incorporated in embankments mainly to reduce the weight of fill across soft foundation areas. Mats of tire sidewalls have been used in embankment to reinforce the fill material. The concept of using tires in embankments is also extended to enhance the stability of steep slopes.

A questionnaire circulated by the author, as part of a synthesis study on the "Use of Waste Materials in Highway Construction" (Ahmed, 1991), indicated that a majority of the United States highway agencies are currently using or experimenting with the use of rubber tires in a variety of highway applications. Of the 44 respondents to the survey questionnaire, 30 state highway agencies reported the use of rubber tires and/or its products in various components of highway pavement. A majority of states reported the use of crumb rubber additive (CRA) in asphalt paving products as a binder (asphalt-rubber) and/or as an aggregate (rubber modified asphalt). A few states reported their experience with the use of shredded tires in embankment/subgrade as a lightweight fill material (e.g., Minnesota, Oregon, Vermont, and Wisconsin). The California State Department of Transportation reported the use of whole tires and tire sidewalls for soil retaining and for soil reinforcement, respectively.

Legislation which is intended to simulate recycling of tires is in force in a number of states and is being debated in others. As of January 1991, thirty six states have passed or finalized scrap tire laws or regulations, and all but 9 states regulate or have bills being proposed to regulate tires (EPA, 1991). The majority of states have imposed regulations that require tires to be processed (cut, sliced, or shredded) prior to landfilling. Whole tire are discouraged from landfilling (in almost all cases) either by law (e.g., Minnesota) or more frequently by high disposal fees. Four states (i.e., Oklahoma, Oregon, Utah, and Wisconsin) have developed rebate programs to encourage recycling or burning for energy, helping stimulate the scrap tire market.

The respondent state highway agencies had generally reported approximate annual quantities of waste materials currently used, which indicated that rubber tires are generally used in small quantities, with a few exceptions (e.g., Arizona, Oregon, and Vermont state highway agencies). The state highway agencies also reported their experiences with the use of waste tires in highway construction from technical, economic, and environmental viewpoints. The author also synthesized the information reported in the literature on the performance of waste tires in highway construction (Ahmed, 1991).

Based on a critical analysis of the information obtained as a result of the questionnaire and a review of the literature, the following conclusions were drawn concerning the use of waste rubber tires in highway construction (Ahmed, 1991):

- Use of asphalt-rubber as a crack/joint sealant seems cost effective in view of its better performance in most of the cases. However, its long term performance must be monitored due to lack of sufficient experience with its use.

- Use of Stress Absorbing Membranes (SAM) reduce the reflection of fatigue cracks of moderate width and thermal cracks; has generally provided longer service life than the conventional surface treatments; and is likely to be equal to the conventional surface treatment on a life cycle cost basis.
- Stress Absorbing Membranes Interlayers (SAMI) have generally not been effective in eliminating the reflection of fatigue cracks. Although some reduction in reflection of cracks has been experienced, the improved performance is not commensurate with the additional cost.
- Asphalt-rubber and rubber modified asphalt mixtures in asphalt pavements have met with both successes and failures. The products need to be further researched to fully understand their behavior prior to their extensive use in the highway industry.
- The initial cost of the asphalt paving products with CRA are generally 50% to more than 100% higher than the products with conventional materials, depending upon the local conditions. The additional cost may be justified over the life cycle, if long term evaluations show that asphalt-rubber and rubber modified asphalt paving products perform better than the conventional materials

and provide longer service lives, which is generally not substantiated by field experience at present.

- The use of CRA in asphalt paving products is generally acceptable from an environmental viewpoint, with some concern about air pollution as a result of adding rubber to the mix and also the requirement of elevated temperatures during mixing of paving materials.
- The use of shredded tires in subgrade/embankment as a lightweight fill material is technically feasible and economically beneficial, as tires are non-biodegradable and large quantities of waste tires can be so consumed. Potential problems include leachates of metals and hydrocarbons. Drinking water Recommended Allowable Limits (RALs) are found to be exceeded under "worst-case" conditions (MPCA, 1990).
- The use of tires for soil reinforcement in highway construction is feasible from technical and economic viewpoints, but may have environmental implications.
- The use of tires in retaining structures is economical and practical, but has aesthetic and environmental implications.
- Feasibility of recycling asphalt paving products containing CRA is not known, due to limited reported experience.

2.3 Source Reduction

Source reduction, i.e., reducing the number of tires generated in the first place, is one of the options to be considered to minimize the tire disposal problem. Source reduction measures for tires include:

Design of longer wearing tires - The development of radial tires and advances in technology have more than doubled the life of tires over the past forty years. Currently 40,000 miles is the usual life of a steel belted radial passenger tire, and sixty to eighty thousand mile life times may be achieved with proper care and maintenance. Further incrases in life would require higher pressure, thicker treads, or less flexible materials. Each of these methods would result in more gas consumption, higher cost, and/or rougher rides. It is, therefore, not expected that any major changes will occur in the near future that will significantly increase tire life (EPA, 1991).

Reuse of used tires - Generally, when one or two tires of a set are worn, the entire set is replaced with new tires. The reuse of those tires that still have serviceable treads can reduce the tire disposal problem. EPA (1991) estimates indicate that currently about 10 million tires are reused, and that reuse could potentially double based on the number of waste tires generated.

Retreading - Retreading is the application of a new tread to a worn tire that still has a good casing. Retreading of worn tires is an efficient, viable procedure for recycling. Retreading began in the 1910's and about 33.5 million tires (18.6 million passenger/light truck and 14.9 million truck tires) were retreaded in 1990. There are over 1,900 retreaders in the United States and Canada; however the number is shrinking because of the decreased markets for the retreads (EPA, 1991). The decline is primarily due to the low price of new tires and the common misconception that retreads are unsafe. Conversely, truck tire retreading is increasing; such tires are often retreaded three times.

2.4 Recycling of Whole Tires and Tire Sidewalls

2.4.1 Soil Reinforcement

Engineers and researchers have a keen interest in methods of reinforcing soil by inclusions possessing tensile strength, and in developing civil engineering materials that are more economical, but otherwise comparable with existing materials. These two apparently contradictory requirements can now be reconciled by the use of rubber-soils. Various agencies, in the United States and abroad, have practiced and evaluated the use of tires for soil reinforcement. Forsyth and Egan (1976) described a method for the use of waste tires in embankments and considered it a very promising application. The method involves separation of tire sidewalls and treads, the latter being a commercially valuable commodity. The tire sidewalls can be used as mats or strips in embankment to increase its stability.

The laboratory and theoretical studies conducted by Caltrans (Forsyth and Egan, 1976) indicated that the systematic inclusion of tire sidewalls could possibly benefit a fill and thus permit steeper side slopes and increase resistance to earthquake loading. Encouraged by the results of these studies, Caltrans designed a tire-anchored wall system, in which tire sidewalls were used to anchor timber retaining structures (Richman and Jackura, 1984; TNR, 1985 and Caltrans, 1986). They are now developing designs to incorporate 6 ft. timber posts obtained from the removal and replacement of guardrail installations.

Construction Incorporated, Youngstown, Ohio, used an innovative method of constructing a road across a swampy area near Niles, Ohio (Biocycle, 1989). They used tire sidewall mats linked with stainless steel strapping as a foundation and found it a practical and economical way of constructing roads across soft patches. The method has been patented under the trade name "Terramat". It is reported that the Terramat system is economical in the areas of soft, unstable, and waterlogged ground. The system is found uneconomical in those areas where embankment foundation soil is strong and does not present a stability problem.

Turgeon (1989) described the experience of the Minnesota Department of Natural Resources in the use of tires for soil reinforcement. They used whole tire mats and tire chunks as a material to replace corduroy logs for road embankments over swamps.

This technology is reportedly spreading to other roadway projects.

In France, a technique to reinforce soil using scrap tires has been developed recently, which is patented under the trade name "Pneusol" (i.e., Tiresoil). The first research in France on the use of old tires to reinforce soils was done in 1976 (Audeoud et al., 1990), which finally led to the development of "Pneusol". It is a combination of soil and tire parts, which may be tied together in chains or placed in layers. The engineering properties of Tiresoil have been studied by the French engineers and the mix has been found suitable for construction of embankments and retaining walls. Tiresoil is found to improve the mechanical properties of soil either anisotropically, i.e., only in the direction in which the material is most highly stressed (layers, linear strips, etc.), or isotropically, i.e., in all directions (the elements mixed with soil).

This application of waste tires is considered practical and economical, but it may have environmental implications, as discussed under Section 3 of this report. The potential problem include leachates of metals and hydrocarbons. Further research is required to develop/standardize design and construction procedures and also determine the long term effects on the groundwater quality of using tires in subgrade/embankment.

2.4.2 Soil Retaining

The use of tires in retaining structures has also been practiced primarily for maintenance and rehabilitation of road embankments (Caltrans, 1988; Nguyen and Williams, 1989; and Keller, 1990). Whole tires anchored in the backfill are used in various configurations for wall heights up to 10 ft. This application is economical, results in moderate face settlement and may have aesthetic and environmental implications.

2.4.3 Erosion Control

Scrap tires lashed together forming large mats have been used to control erosion along highway slopes, coastal roads, drainage channels, etc. The California Office of Transportation Research has investigated several erosion control applications of scrap tires. Discarded tires were banded together and partially or completely buried on unstable slopes in tests conducted between 1982 and 1986. They found this application of waste tires practical and economical. Construction costs were reduced from 50 to 75 percent of the lowest cost alternatives such as rock, gabion, or concrete protection. It is reported that less than 10,000 tires are used annually for this application in California (EPA, 1991; Nguyen and Williams, 1989; and Williams and Weaver, 1987).

Scrap tires have also been used for shoreline protection. On the Eastern shore of Maryland, a scrap tire revetment has been constructed by stacking tires four high and anchoring the tires into the ground with fiberglass pins. The cavity is filled with soil and a plug of dune grass to promote vegetation and hide the revetment. The method appears to be successful in coastal areas with moderate tides and limited wave action. The costs are estimated at about US $40 per linear foot compared to about US $100 per linear foot using conventional shoreline protection methods (Crane, et al., 1978).

2.4.4 Sound Barriers

Rubber tires have good sound insulation characteristics. The Wisconsin Department of Transportation has recently constructed an embankment along a highway to investigate the use of tires for noise reduction. If their trials support this usage of tires, large quantities of scrap tires can be consumed in this application along highways passing through major cities or built up areas. However, proper coverage of the tires would be required for safety against fire and from an aesthetic point of view.

2.4.5 Crash Barriers

The use of scrap tires as crash barriers was investigated in the late 1970s by the Texas Transportation Institute. They found that stacked tires bounded by a steel cable and enclosed with fiber glass would reduce or absorb impact of automobiles traveling up to 71 miles per hour (Hirsch and Marquis, 1975; Marquis, et al., 1975; and Caltrans, 1975). Their report concluded that it was both technically and economically feasible to use scrap tires as vehicle impact attenuators. However, this application of waste tires has not been very popular basically for two reasons: (1) on impact the tires are likely to spill onto the highway and may be a safety risk for other traffic, especially from the opposite direction; and (2) the highway community generally prefers sand-filled crash barriers because they have excellent absorption characteristics and are easier to construct.

2.4.6 Breakwaters

Breakwaters are off-shore barriers that are constructed to protect the harbor or shoreline from the full impact of the waves. Breakwaters using scrap tires were tested by US Army Corps of Engineers and were found to be effective for smaller waves (EPA, 1991). Floating breakwaters have also been investigated, and are found to be more effective (OECD, 1980). Floating breakwaters are constructed by partially filling tires with foam rubber, and lashing them together in modular bundles. They have excellent energy absorbing characteristics. The cost estimates vary and depend on: the design life; material, labor, and transportation costs; and local conditions.

2.4.7 Artificial Reefs

Waste rubber tires have been used to build artificial reefs to provide homes for all sorts of aquatic life. Scrap tires are preferred for this application because of many factors, including: their low cost, longer service life, large surface area, ease of design and construction, and a convenient method to dispose of large quantities of tires. The United States Bureau of Sport, Fisheries, and Wildlife (BSFW) has been experimenting with artificial reefs made from used tires since 1965. BSFW estimates that artificial reefs could absorb all scrap tires generated in the United States. Malaysia is currently seeking 35 million tires to use as a breakwater barrier and reef (Ruth, 1991). However, artificial reefs are labor intensive and quite expensive to construct. The estimated reef construction cost is US $2.69 per tire, including collection, handling, and transportation costs (OECD, 1980). The benefits of artificial reefs include: increased recreational fishing facilities, avoiding tire disposal costs, positive impact on environments, and stimulating commercial fisheries. However, the long term effect of artificial reefs on the ocean environment is unknown.

2.4.8 Miscellaneous Uses

Scrap Tires as Playground Equipment - A small amount of scrap tires are used for this purpose. This application of waste tires is practical and economical, but not very popular. People generally prefer wooden playground equipment, where economics is not a consideration.

Splitter Industry - The splitter industry utilizes scrap tires that are rejected by retreaders. The industry is mature and dates back to 1915. They use approximately 50 million pounds of scrap tires per year to manufacture useful articles such as gaskets, shims, or ribbons from which floor mats and dock bumpers are fabricated. This usage is equivalent to about 3 million scrap tires. Although a good growth rate is predicted, the volume of scrap tires used by this industry will not absorb a large percentage of the supply (OECD, 1980).

2.4.9 Landfilling/Stockpiling

Burying tires in landfills has been the most common method of tire disposal in the past. However, tires occupy a large landfill space due to low bulk density and they have a tendency to rise up to the surface. In addition, existing landfills are fast diminishing and new landfills are difficult to site. In Indiana, 12 years ago, there were 150 landfills. These have diminished to 78, with a life span to less than seven years each. Several states have considered or are considering legislation that would completely ban disposal of whole tires in landfills. Landfilling of whole tires is discouraged either by law or more often by high disposal fees, or by requiring that tires be disposed of in tire monofills.

Stockpiling of tires may be unsightly and hazardous. Tire stockpiles hold stagnant water which provides an ideal breeding ground for disease carrying insects and other vermin. The most obvious hazard in stockpiling is the potential for fire. In 1984, a 1.5 million tire stockpile caught fire and burned out of control for seven months (Civil Engineering, 1989). The fire left 5 acres of ash and metals containing hazardous waste which proved to be extremely difficult to clean up by conventional methods. The environmental and economic problems associated with landfilling and stockpiling of scrap tires have stimulated the pursuit for non landfill disposal, recycling, and reuse of scrap tires.

2.5 Shredded Tires Applications

Tires are shredded for several applications, including shredding prior to landfilling/incineration. The majority of scrap tire disposal procedures require some degree of size reduction. A significant transportation and handling cost savings can be realized by increasing the bulk density of scrap tires, i.e., by size reduction. Several types of commercial choppers/shredders have been developed, which can reduce a tire, including beads and steel-belts, to a particle range of several centimeters to fractions of a centimeter. The larger particle size range is generally required if the scrap rubber is to be landfilled. The small particle size range is generally used when the scrap rubber is to be further processed for various applications, including crumb rubber production. Some of the applications of shredded tires, which have been used over the years with varying degrees of success, are described below.

2.5.1 Lightweight Fill

Construction of roads across soft soil presents stability problems. To reduce the weight of the highway structure at such locations, wood-chips or saw dust have been traditionally used as a replacement for conventional materials. Wood is biodegradable and thus lacks durability. Conversely, reclaimed rubber tires are non-biodegradable and thus are more durable. Other potential benefits of using shredded tires as lightweight fill in embankments founded on weak, compressible foundations are: reduced weight of fill; generally an economical alternative to conventional materials; a free draining material, so there are no problems with build up of excess pore pressure; conservation of natural resources; and recycling of large quantities of locally available waste tires. Tire chips can replace the existing material in a slide prone areas to reduce the weight on foundation soil, and thus improve stability of slopes.

Various agencies, in the United States and abroad, have evaluated the use of shredded tires as lightweight fill material in a variety of different ways, i.e., chips mixed with soils, layered with soils, or pure chips. Their experience and findings from the research support the use of properly confined tire chips in highway applications (Section 3 summarizes the experience and research in the use of chips as lightweight fill). This application of waste tires is considered practical and cost effective (cost of tire chips is generally competitive with wood chips). However, it may have environmental implications, as discussed in Section 3.

2.5.2 Synthetic Turf

The feasibility of using scrap rubber as a component in synthetic turf for playgrounds, factory floors, park paths, etc., has been investigated in the past. Goodyear announced a new product called Tire Turf (Anderson, 1972) which is prepared by mixing shredded tires (bead-free) with a binder, such as polyurethane, latex, or asphalt. The Tire Turf is laid like concrete and cures overnight. The turf has good anti-slip properties and can be laid around swimming pools. The turf is usually covered with a fireproof material and is stated to be both fungus- and rot-proof. Long term durability data concerning this material are not available.

2.5.3 Playground Gravel Substitutes

Some of the companies (e.g., Baker Rubber, Inc., South Bend, Indiana; Waste Reduction Systems in Upper Sandusky, Ohio; and Safety Soil of Carmichael, California) are producing tire chips for use as gravel substitute in playgrounds and running tracks. Tires are shredded to sizes ranging from 1/4 in. to 5/8 in. All steel from the tire chips is removed by using magnets. The benefits of using rubber chips in and around playground equipment include: provide a better cushion than conventional materials, e.i., gravel, stones, wood, etc.; are more durable; provide cleaner environments; are free draining material; and are cost competitive on a life cycle basis. However, tire chips have a higher initial cost and are potentially combustible, thus requiring additional precautions against fire.

2.5.4 Oil Spills

Shredded rubber tires in combination with polystyrene scrap have a good capacity for absorbing oil and can be used for cleaning up oil spills (Beckman, et al., 1974). After absorbing oil, the mixture is heated to form an asphaltic material that is claimed to be useful for road building (to avoid a secondary disposal problem).

Koutsky, et al. (1977) conducted a laboratory study to determine the oil absorbing capacity of rubber particles. They used the rubber particles sizes ranging from sieve #70 to 20, obtained from cryo-hammer mill process using old tires as the stock material. They experimented with rubber particles used alone and rubber particles mixed with wood fines. They found that the oil up-take of rubber particles was affected by particle size, temperature and type of oil. Mixing of rubber with wood shavings imparts cohesion to the mix, which facilitates drawing of mix into a collection device. The study concluded that rubber particles can be efficiently and economically used for oil spill recovery.

2.5.5 Shredded Tires for Sludge Composting

Shredded tires have been used as a bulking agent in the composting of waste water treatment sludge (EPA, 1991). The 2 inch square chips are mixed with the sludge to maximize air flow through the compost pile. The chips are then removed from the compost and recycled prior to its sale or use. The high initial cost of chips is the major disadvantage associated with this application of shredded tires.

2.5.6 Shredded Tires as Mulch

Traditionally, wood chips or straw has been used as mulch for landscaping along highways. Shredded tire chips can be used for this purpose. Tire chips are more durable and would require less frequent replacement. However, steel will have to be removed from the chips, which is likely to make this product more expensive than wood chips.

2.5.7 Building Products

Rubber Research Elastomeric of Minneapolis produces a product called Tirecycle, made from shredded tires and new rubber, for use in automobile truck liners, floor mats, and dashboards (Cindy, et al., 1990).

Another waste tire recycling process being developed is called "reclassification" and involves shredding, pyrolysis (see Subsection 2.5), and purifying tire components and results in by-products of carbon black, oil, and gas. This is a patented commercial process developed by American Tire Reclamation, Inc. This company has plants in Oregon, Ohio, and Pennsylvania, each of which are expected to process about 5,000 tires per day (Cindy, et al., 1990).

Research is underway on a variety of products using reclaimed shredded rubber to produce items such as containers, plants, fence posts, and domestic drain pipes. J & J Trading, Inc. of Chester, Pennsylvania claims that the shredded rubber is cheaper than any raw material used in manufacturing drain and sewer pipes (Elastomerics, 1989).

2.5.8 Chemical Uses

Chemical uses of scrap tires include the controlled chemical treatment of scrap tires permitting the recovery of certain original or related chemical constituents. All chemical processes involve the initial reduction of whole tires to smaller sized chips. The chemical composition of a scrap tire as expressed by product or element analysis is quite variable and is difficult to specify. However, major components of a typical worn (steel-free) tire are: rubber (50%), carbon black (27.5%), and oil (17.5%). An approximate chemical analysis of a scrap tire is carbon, 83%; hydrogen, 7%; oxygen, 2.5%, sulfur, 1.2%; and nitrogen, 0.3%. The remaining is nonvolatile ash (Crane, et al., 1978).

Destructive Distillation, Carbon Black Recovery and Hydrogenation - It is possible to recover the various constituents of scrap tires, using various chemical processes. Two of the processes, i.e., destructive distillation and carbon black recovery, are forms of pyrolysis. Hydrogenation is a process of chemical synthesis. It involves addition of hydrogen to rubber to make chemicals from which new elastomers can be produced. In pyrolysis, tire ingredients (i.e., carbon, hydrogen, ash) are yielded in chemically complex oils and gases, and a solid residue. Depending on the operating temperature, the proportion of oil, gas, and residue can be varied. High temperature (i.e., 900°C) pyrolysis yields large quantities of residue, much of which is carbon black. Whereas, lower temperature pyrolysis yields large quantities of oils, mostly olefins, aromatics, and naphthenes (OECD, 1980). Pyrolysis of waste tires is a rapidly developing technology. The rising cost of petroleum feedstocks for producing elastomers and recycling of waste tires are the main incentives for improving the process. Although, many experimental pyrolysis units have been tried, none has yet demonstrated sustained commercial operation (EPA, 1991).

Reclaimed Rubber - A commercial description or definition of reclaimed rubber is: the product resulting from the treatment of ground vulcanized scrap rubber tires, tubes and miscellaneous waste rubber articles by the application of heat and chemical agents, followed by intense mechanical working, whereby a substantial "devulcanization" or regeneration of the rubber component to its original plastic state is effected, thus permitting the product to be compounded, processed and revulcanized (Smith, 1978). Reclaiming is essentially depolymerization; the combined sulfur is not removed. The product is sold for use as a raw material in the manufacture of rubber goods with or without admixture with natural or synthetic rubber. The market for reclaimed rubber depends upon its cost of production and upon its quality relative to virgin rubbers. The relatively small proportion of reclaimed rubber used in new tire production is due to a technological problem. With existing blending technology, reclaimed products cannot be used in proportions greater than 1% to 2% for higher performance tires (OECD, 1980).

Asphalt and Fuel Production - The New Paraho Corporation of

Denver, Colorado, has initiated a program to investigate the feasibility of producing high quality asphalt and fuel from the pyrolysis (destructive distillation) of oil shale with five percent scrap tires. The concept is to market the asphalt as an additive to improve the properties, particularly moisture susceptibility, of standard petroleum-based asphalts, and thereby make the process cost effective. The potential benefits associated with the co-processing of spent tires with oil shale include the relatively high oil content of tires per unit weight in comparison to oil shale and the higher percentage of naphtha (gasoline), making this oil more valuable as a refinery feedstock. A pilot plant is built to investigate the properties of this co-processed material. If the pilot plant study shows the process is profitable and a full-scale plant is built, it is likely to consume most scrap tires produced in the state of Colorado (Cindy et al., 1990).

2.5.9 Storage/Monofills

Landfilling of whole tires is discouraged in almost all the states. Whereas, stockpiling of whole tires is hazardous (see Subsection 2.3.9), a majority of states have imposed regulations that require tires to be processed (cut, sliced, or shredded) prior to landfilling. However, this is wasteful of the country's natural resources. Kurker (1977) has suggested a procedure for stockpiling whole or chopped scrap tires until economical processes are commercialized. In the writer's opinion, monofills of shredded tires may be a comparatively better option than landfilling/ stockpiling of whole tires. The possible advantage to this arrangement would be time, allowing a disposal technology to be forthcoming that would convert the scrap tires to a high-value product. However, shredding would cause additional costs and proper preventive measures would be required against fire, since stockpiles would be a great fire hazard.

2.6 Crumb Rubber Technology

2.6.1 Crumb Rubber Production

The most common technology used to convert scrap tires into crumb rubber is with shredders and grinders operated at ambient temperatures. There are currently 15 companies in the United States which produce crumb rubber through ambient grinding (Spencer, 1991). These facilities use various combinations of shredders, magnets, granulators, cracker mills, and screening equipment to produce crumb rubber, steel, and fiber from scrap tires.

Crumb rubber is produced basically using three methods (Heitzman, 1992): (1) crackmill process - this process tears apart scrap tire rubber, reducing the size of the rubber by passing the material between rotating corrugated steel drums and it is the most common method; (2) granulator process - shears apart the scrap tire rubber, cutting the rubber with revolving steel plates that pass at close tolerance; and (3) micro-mill process - it further reduces a crumb rubber to a very fine particle size. As the scrap tire rubber is processed, reducing its size, the steel belting and fiber reinforcing is separated and removed from the rubber. Typically, 50% to 60% of crumb rubber is recovered from scrap tires.

Each method of producing crumb rubber generates unique particles with specific characteristics. The cracker mill process produces an irregularly shaped torn particle with a large surface area. The particles can be produced over a range of sizes from 4.75 mm to 425 μm (sieve No. 4 to No. 40), commonly described as a ground CRA. The granulator produces a cubical, uniformly shaped cut particle with a low surface area. Typical range of particles sizes is from 9.5 mm to 2.00 mm (3/8 in. to sieve No. 10). This material is called a granulated CRA. The micro-mill process produces a very fine ground CRA, with particles sizes ranging from 425 μm to 75 μm (sieve No. 40 to No. 200; Heitzman, 1992).

Tires can also be ground by a "cryogenic" method. Cryogenics is defined by the Webster's Dictionary as "the science that deals with the production of very low temperatures and their effects on the properties of matter." When extremely cold conditions are applied to tires, usually with liquid nitrogen, the rubber is cooled to a point where it becomes brittle.

In a typical crumb rubber production plant using the cryogenic method, the cooled tire pieces drop into a hammermill to be fractured into crumb rubber, steel, and fiber. A shaking screen separates fiber and steel from the rubber granules; a magnetic separators removes steel. Next the rubber granules are transported by a conveyor/dryer to remove excess moisture, which allows easier separation of remaining fiber, and separation of rubber granules by particle size. The complete rubber granules stream passes through a secondary magnetic separator and then is classified by means of a shaker screen into various mesh sizes ranging from greater than sieve No. 5 to less than sieve No. 40. The oversized material is then processed through a granulator to reduce the particles to the desired gradation. The principal benefit reported from cryogenic grinding is that the product is not thermally and/or oxidatively degraded to any appreciable extent (Crane, et al., 1978).

2.6.2 Crumb Rubber in Asphalt Paving Products

"Crumb Rubber Additive" (CRA) is the generic term for the product from scrap tires used in asphalt products. It is the product from "ambient" grinding of waste tires and retread buffing. Tires ground by "cryogenic" method can also be used in asphalt. However, mixed opinions are expressed about their suitability as CRA (Bernard, 1990; Biddulph, 1977). Addition of CRA to asphalt paving products can be divided into two basic processes: (1) wet process - blends CRA with hot asphalt cement and allows the rubber and asphalt to fully react in mixing tanks to produce an asphalt rubber-binder; (2) dry process - mixes CRA with the hot aggregate at the hot mix asphalt (HMA) facility prior to adding the asphalt cement to produce a rubber modified asphalt mixture. The four general categories of asphalt paving products which use CRA include: crack/joint sealants, surface/interlayer treatments, HMA mixtures with asphalt-rubber, and rubber modified HMA mixtures.

Crack/Joint Sealant

Crack/Joint sealant may be an asphalt-rubber product, blending 15% to 30% CRA with the asphalt cement. It is covered in the American Society for Testing and Materials (ASTM) specifications (ASTM D3406) and it is routinely used by many state highway agencies. The performance of asphalt-rubber as a crack/joint sealant is generally found to be satisfactory. Asphalt-rubber crack/ joint sealant is typically preblended and packed in 50lb blocks. These blocks are remelted and "reacted" before the sealant is applied. Stephens (1989), based on nine-year evaluations of field performance of asphalt-rubber as joint sealant, reported that site-mixed materials performed better than pre-mixed materials.

Surface/Interlayer Treatments

Surface/interlayer treatments may use an asphalt-rubber binder with 15% to 30% CRA. This application of CRA began in the late

1960s and was patented under the trade name SAM (Stress Absorbing Membrane) and SAMI (Stress Absorbing Membrane Interlayer).

SAM - It is a trade name for a chip-seal with an asphalt-rubber sealant. The purpose of this layer is to seal the underlying cracks, thereby preventing the entry of surface water into the pavement structure. It is also intended to absorb the stresses that would lead the underlying cracks to reflect up to the surface. It is formed by applying asphalt-rubber on the road, covering it with aggregate and seating the aggregate with a roller. The thickness of the application usually varies from 3/8 to 5/8 in. (Singh and Athay, 1983), and 0.5 to 0.65 gallons per square yard of binder is applied to the surface. Another approach to the construction of a SAM is to proportion and mix the asphalt-rubber material and chips in a conventional asphaltic concrete spreading machine. However, the cast-in-place SAM's have performed better (Vallerga, et al.,1980).

SAMI - It is a layer, with an asphalt-rubber binder, sandwiched between the road base and an overlay. The only difference between SAM and SAMI is that SAM does not have an overlay whereas SAMI does. The intended purpose of SAMI is to reduce reflection cracking by cushioning or dissipating the stresses from the underlaying pavement before they are transferred to the overlay. The procedure in placing the SAMI is similar to that used in placing the SAM, with a few differences in design aspects.

Impermeable membranes - The concept of SAMI's has been extended to the use of impermeable asphalt-rubber membranes, that are laid between subgrade and subbase/base, and have proved successful for controlling moisture in subgrade soils. The membranes help reduce evapotranspiration of moisture from the subgrade and infiltration of moisture from surface runoff. In the case of expansive soils, variations in moisture content can lead to large volume changes, which may cause development of cracks in the pavement, thus reducing pavement service life and also creating hazardous driving conditions. The asphalt-rubber membranes have been used on northwestern Arizona highways, which are mostly laid on expansive clays (Walsh, 1979). Field observations and objective measurements indicate that the membrane treatment has improved pavement performance.

Asphalt-Rubber Mixtures

The use of asphalt-rubber binder in HMA mixtures has been researched in the USA for the past 40 years. In early 1960's, Charles McDonald, Material Engineer for the City of Phoenix began working with a local asphalt company, Sahuaro Petroleum, to develop a highly elastic maintenance surface patch using CRA. In 1968, the Arizona Department of Transportation (DOT) placed its first SAM (Scofield, 1989). The Arizona DOT placed their first SAMI in 1972 and used the CRA modified binder in HMA open graded friction course in 1975. As the Sahuaro technology continued to expand, the Arizona Refinery Company (ARCO) developed a similar "wet process" technology which added a blend of CRA and de-vulcanized CRA to the asphalt cement. Eventually the Sahuaro and ARCO technologies merged and are presently controlled by the patents' co-owners. Today, the "wet process" developed in Arizona, is referred to as the McDonald technology. The amount of CRA in asphalt-rubber binder for HMA applications generally range from 15 to 25 percent by weight of asphalt cement (Heitzman, 1992).

Conventional Marshall and Hveem mix design procedures have been used successfully for dense graded mixes using McDonald's asphalt-rubber technology. The characteristics of the modified binder alter the laboratory measured properties of the mix and should be considered while designing these mixes. Typically, the increase in the designed binder content is proportional to the amount of CRA in the binder. The design concept being developed for modified gap graded mixes is to maximize the asphalt-rubber content of the mix. Typical asphalt-rubber content for gap graded mixes range from 8 to 9 percent (Heitzman, 1992). The reported benefits of using asphalt-rubber HMA mixes include (McQuillen and Hicks, 1987): flexibility down to -26°C (-15°F); higher viscosity than conventional asphalt at 60°C (140°F); tougher (in relation to surface wear from studded tires) and a more elastic surface; greater resistance to aging; and recycling of used tires.

Rubber Modified Asphalt

The concept of introducing coarse rubber particles into asphaltic pavements (using the dry process) was developed in the late 1960s in Sweden. It was originally marketed by Swedish Companies under the patented name "Rubit". This technology was introduced in the United States in the 1970s as the patented product, PlusRide (Bjorklund, 1979; Allen and Turgeon, 1990). The Alaska DOT began working with PlusRide in 1976 and is still the principal highway agency developing this technology. Three corporations have marketed the PlusRide technology since it was introduced in the United States, presently it is the PAVETECH Corporation (Heitzman, 1992).

The PlusRide process typically uses 3% by weight granulated coarse and fine rubber particles to replace some of the aggregates. The mix design for PlusRide does not follow normal Marshall or Hveem procedures (Takallou and Hicks, 1988). The PlusRide HMA is designed to modify the stability of a gap graded aggregate matrix with the elastic properties of CRA and a certain amount of binder modification. Conventional specimen preparation equipment and procedures are performed with some modifications, but the specimens are not tested for stability. The only measured specimen property used to establish the mix design asphalt content is percent air voids. The target air void content is 2 to 4 percent (Heitzman, 1992). The reported advantages of using the PlusRide in HMA applications are (PlusRide, 1984; reported by McQuillen and Hicks, 1987):

- reflective and thermal pavement cracking are greatly reduced;
- resistance to studded tire wear is increased;
- skid resistance is increased;
- ice removal by elastic deformation of the rubber granules under traffic loading and vehicle generated wind;
- suppression of pavement tire noise; and
- recycling of used rubber tires.

Discussion on the Use of CRA in Asphalt Paving Products

Various laboratory, field, and analytical studies (e.g., Esch, 1984; Lundy, et al., 1987; McQuillen, et al., 1988; Takallou and Hicks, 1988; Schnormeier, 1986; Takallou, et al., 1985; 1986; and 1989; and Vallerga, 1980) and industry publications (e.g., PlusRide, 1984; Arm-R-Shield, 1986) indicate that adding CRA to asphalt paving products (as a binder or as an aggregate) improves the engineering characteristics of pavements, including the service life. However, a careful analysis of information obtained as a result of the questionnaire survey (Ahmed, 1991) and scrutiny of the published literature indicated that these claims are not always substantiated by the field performance of asphalt paving products containing CRA. The experience in the use of CRA in asphalt paving products showed both successes and failures.

The experience of a number of states in the use of CRA in different categories of asphalt paving products was studied to establish the basic causes of observed failures (see Ahmed (1991) for the experiences of a number of states in the use of asphalt paving products). However, it appeared that, with a few exceptions, the failures and successes had been random and no definite reasons could be established for this unusual behavior (i.e., same percentage of CRA used in a similar product, under similar climatic environments demonstrated different behavior - one failed within a short time of construction, whereas, the other performed much better than the control sections). Various reasons have been offered for the inadequate performance of the products (e.g., NYSDOT, 1990; ODOT, 1990). The author is of the opinion that more research (analytical, laboratory, and field studies) is required to completely understand this technology.

It has been found (Ahmed, 1991) that asphalt paving products with CRA have also demonstrated consistently better performance in some states, e.g., Alaska (rubber modified asphalt) and Arizona (asphalt-rubber). Similarly, some of the asphalt paving products have displayed better performance in most of the cases and suffered fewer failures, which include two products that use asphalt-rubber binder, i.e., crack/joint sealant, and SAM.

Various studies on the economics of using CRA in asphalt paving products (e.g., KDOT, 1990; McQuillen et al., 1988; NYSDOT, 1990, Heitzman, 1992) show that the products are not cost effective, since the performance of the products is generally not commensurate with large increases in cost (the increase in cost, for all the categories, i.e., products from asphalt-rubber and rubber modified asphalt, is generally 50% to more than 100% higher than the conventional materials). However, the additional cost of asphalt-rubber as a joint/crack sealant is justified in view of better performance. Similarly, additional cost of materials used in SAM's has also been acceptable based on the life cycle cost in most of the cases, due to its somewhat better performance and generally longer service life.

The asphalt paving products containing CRA are generally acceptable from an environmental viewpoint. A recent study (Rinck and Napier, 1991) indicates that the risk to paving workers associated with its use are negligible. However, concerns are still expressed by some state highway agencies over increased air pollution and safety during blending, mixing, and laydown due to adding rubber to the mix and also the requirement of elevated temperatures during mixing.

The recycling of asphalt pavement has gained wide popularity due to obvious economic and environmental benefits. Research studies have generally not addressed this issue (limited studies have been performed, but conclusions can not be generalized, e.g., Charles, et al., 1980) in the case of asphalt-rubber or rubber modified asphalt. If these pavements cannot be recycled on completion of their service lives, the disposal of these pavements will create another major waste disposal problem.

2.6.3 Miscellaneous Uses of Crumb Rubber

Sound Attenuation - A property of ground scrap rubber which has not been fully exploited commercially is sound attenuation. The research conducted by the Firestone Tire & Rubber Co. has revealed that ground scrap rubber in various paints and coatings can significantly reduce sound transmission of substrates coated with the mixture. The products are directed for use in areas where noise is a problem (Beckman, et al., 1974).

Crumb Rubber in Concrete - Ground scrap rubber has been tried in Portland cement concrete. The product is of lower density than regular concrete and has both lower abrasion and lower compressive resistance. Cured rubber/concrete tends to pulverize rather than chip on impact and does not polish as easily as conventional concrete, but is more easily cut with a saw. Rubberized concrete could find its use in architectural applications where light weight and ease of fabrication are important (Beckman, et al., 1974)

2.7 Incineration/Co-firing

Scrap tires make an excellent fuel source with an estimated heating value ranging from 12,000 to 16,000 Btu/lb (EPA, 1991), with an average of 14,000 Btu/lb, compared to coal and municipal wastes fuel values of 12,000-12,600 Btu/lb and 2,500-8,500 Btu/lb, respectively (Beckman, et al., 1974). Scrap tires, in a well engineered and competently operated plant, can be blended with municipal waste or coal to improve their fuel value (heating value of a scrap tires and municipal waste mix approaches 10,000 Btu/lb). Proven technology exits to efficiently burn whole, shredded, or granulated tires, while meeting all applicable pollution control codes. However, size reduction of tires (i.e., shredding, chopping, splitting) and strict environmental laws may make tire combustion more expensive, due to substantial processing costs and requirement of sophisticated emission control devices, respectively.

Most of the plants currently burning tires for fuel do not have the capability to burn whole tires. Instead they must burn tires that have been shredded into small chips. In this form it is known as tire-derived fuel (tdf). The sizes of chips can vary from 2 to 6 inches, depending on the shredding operation and the user's requirements. Typically, the shredded tire chips also contain steel wires from the tire beads and steel belts. Removal of the steel wires involves an expensive process, requiring fine shredding and the use of powerful magnets, which makes tdf considerably more expensive. In 1990, about 25.9 million tires (10.7% of total generation) were burned for energy production. The use of tires and tdf in various combustion facilities is briefly discussed below (EPA, 1991):

Power plants - Waste tires utilization in tire burning plants has been mainly initiated by Oxford Energy, a company which is headquartered in Santa Rosa, California. The largest scrap tires combustion system is the Oxford Energy plant in Modesto, California, which consumes 4.9 million tires and generates 14 MW of power (EPA, 1991). A second Oxford Energy power plant, designed to burn about 9-10 million tires per year, is under construction in Connecticut. This plant, when completed, will be the largest tire combustion facility in world. In addition, the company has also announced plans to construct two more plants capable of burning large quantities of scrap tires.

Tire manufacturing plants - Two Firestone tire plants have installed pulsating floor furnaces to dispose of scrap tires and other solid waste. These plants, located in Des Moines, Iowa, and Decatur, Illinois, were built in 1983 and 1984, respectively. Each of the incinerator has the capacity to burn 100 tons waste per day, 25% of which is whole tires and scrap rubber. However, tires account for 80% of the Btu consumed by the furnaces. The Des Moines plant was shut down in 1987 for exceeding opacity limits. This plant burns large tires, which are difficult to burn without opacity problems. The plant requires addition of a baghouse, which is not economically feasible. However, no problem has been encountered in burning passenger tires in the Decatur plant (EPA, 1991).

Cement Kilns - Seven cement kilns in the United States utilize about 6 million scrap tires per year to replace conventional fuel. Cement kilns seem to be very suitable for scrap tires because of their high operating temperatures (2,600 °F) and good conditions for complete combustion, which minimize air pollution problems. In addition, there is no residue, since the ash is incorporated into the cement product. Of the 240 cement kilns in the United States, about 50 are equipped with precalciner/preheaters, making them most suitable for tire combustion (EPA, 1991).

Pulp and paper plants - Many furnaces designed to burn wood chips at pulp and paper plants are suitable for burning tdf without major modifications. Frequently, only wire-free tdf can be used in these boilers, thus increasing the tire processing costs. An estimated 12 million tires per year are currently being consumed by the pulp and paper industry (EPA, 1991).

Small packages steam generators - There is currently only one small package generator operated in the United States, which is a Japanese system. The generator is operated by Les Schwab Tires, a retreader in Prineville, Oregon. The generator has been in operation since 1987 and uses 25 tires per hour. An other unit has been manufactured in Italy by Eneal Alternative Energy of Milan, which can burn 200 tire per hour and produce 22,000 pounds per hour of process stream (EPA, 1991).

Tire combustion facilities and the consumption of waste tires in the existing tires-to-energy plants indicate increasing trends.

Whole tires may be incinerated directly or they can be shredded and incinerated as a fuel supplement. The factors which may make tire combustion cost effective include: less requirement of size reduction, as it eliminates the need for expensive processing; location of tire combustion facility in geographic areas of high scrap tire density, to reduce handling and transportation costs; capability of plant to burn efficiently whole tires or tdf with least modifications to the existing facility to reduce initial costs; less stringent environmental laws, as the use of sophisticated emission control devices may increase initial and maintenance costs. Incineration of tires offers solution to tire disposal problem. However, it may not always be economical to burn large quantities of tires in an environmentally acceptable manner.

2.8 Discussion

The various options used in the past, with varying degree of success, to reduce the scrap tire disposal problem are described in the preceding subsections. A scrutiny of these options suggest that no single option or process can solve the tire disposal problem. Various options need be tried simultaneously to overcome this problem. A careful review of available options, suggest that the available options broadly fall into five categories: (1) source reduction; (2) use of tires and their constituents in highway applications; (3) recycling tires into non-highway applications; (4) storage of shredded tires; and (5) combustion of tires and tdf.

Source reduction can be achieved by taking a number of measures, including: improved maintenance of tires; design of longer wearing tires; reuse of used tires; and retreading. Under-inflation, severe braking, fast acceleration, and sharp turning may cause tires to wear out sooner than their usual service life. Conversely, proper maintenance and careful driving will increase their useful life. The development of radial tires has more than doubled tire life. At this point in time, a substantial increase in the tire life is not considered technically and commercially a viable option. However, reuse and retreading of tires is likely to significantly reduce the generation of scrap tires. Some of the measures to promote reuse/retreading of tires include: public education to produce better appreciation of the tire disposal problem, and to decrease their apprehensions/fears concerning poor quality/safety of retreaded tires; improving quality of retreaded tires; development of resource recovery system; regulatory requirements; and economic incentives.

Various highway and non-highway applications of tires and their components are summarized in Figure 2.1. Among the various highway applications: use of CRA in asphalt pavements; shredded tires in embankments as lightweight fill; and tires/components in subgrade/embankment for soil reinforcement hold significant promise for consuming large quantities of tires, with considerable engineering benefits. These applications were discussed in some detail in previous subsections. However, each of these

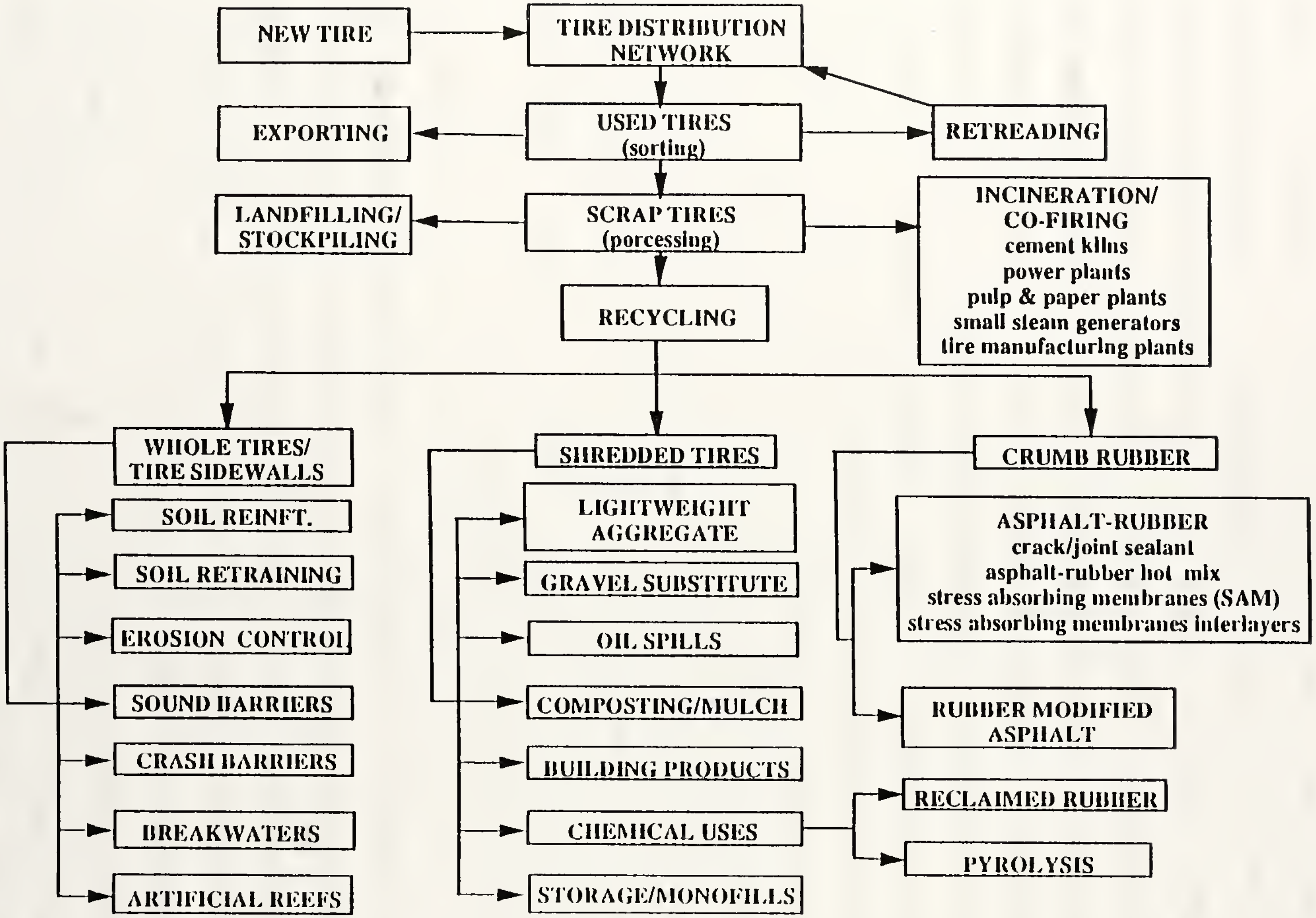

Figure 2.1: A Summary of Recycling and Disposal Options for Scrap Tires.

applications has technical, economical, and environmental implications, which need to be addressed prior to its extensive use in highways.

The non-highway applications which can consume large quantities of tires and have potential for further development, include: breakwaters, artificial reefs, and reclaiming of rubber and other product through chemical reclaiming processes and pyrolysis. Although all these applications have been experimented with in the past, currently none of these applications is commercially viable. Although, the other applications included in Figure 2.1 (e.g., soil retaining, erosion control, sound barriers, building products) are not likely to expand substantially in the near future, they are contributing positively in solving the tire problem. Therefore, use of tires and its products in other applications should also be encouraged.

Stockpiling of tires in the open is unsightly, is a fire hazard, and creates a breeding ground for mosquitoes. It is not legal in most states. However, storage of shredded tires in covered installations or monofills, with adequate measures against any adverse impact on environments is a viable option, allowing conservation of this valuable material. Further technological advances can convert this material into a valuable product, or a rise in the cost of petroleum feedstock may make reclaiming and pyrolysis commercially viable processes. Storage of shredded tires, in an environmentally acceptable manner, may be preferred over combustion of tires.

Scrap tires, with heating value slightly higher than coal, make an excellent fuel source. Usually tires are shredded or chopped (generally called tdf) and then burned alone or mixed with coal. Of the currently available tire-to-energy facilities, power plants, cement kilns, and pulp and paper plants hold a greater promise to burn the tdf efficiently and in environmentally acceptable manner. However, it may be noted that tires are highly durable, lightweight, and have intrinsically high tensile strength. These properties make tires a useful engineering material. Burning of tires is considered a waste of natural resources and is not a beneficial use of scrap tires. This option may be resorted to sparingly and under the circumstances that no recycling option can be practically exercised.

2.9 Conclusions

This section summarizes the various options available to reduce the scrap tire disposal problem and also benefit from recycling of this highly durable engineering material (see Figure 2.1 for a summary of available options). Broadly, the various options include: the reduction of waste tire generation; reuse of chemically unaltered material, in whole tires or after processing; the reclaiming of rubber, constituent materials, or chemicals from scrap tires to recycle them in the manufacture of new products; and the recovery of heat value. Of all the options currently available for the disposal of scrap tires, no single option appears to be so outstanding which can significantly minimize the tire disposal problem, economically and also in environmentally acceptable manner. Many options/processes need to be simultaneously tried and developed to solve the problem.

A careful review of the currently practiced tire reduction/ recycling options/processes, led to the following salient conclusions:

- Waste tires may be recognized as a valuable raw material. The factors which favor recycling and must be exploited, include: high physical durability, elastic in nature, intrinsically high tensile strength, lighter in weight, high heating value, low costs, and positive effect of recycling on environments. Factors which are impediments to recycling and must be considered while exploring/trying various recycling processes, include: inherently complex chemical composition and manufacturing process, which makes them bulky, resilient, nonbiodegradable, and potentially combustible; variability within the same type and also within different categories of tires; and questionable leachates under adverse environmental conditions.
- Of the available options in source reduction (i.e.,

longer service life, reuse, and retreading), reuse and retreading are economically/commercially viable and environmentally desirable options. Retreading holds greater promise for significant reduction in waste stream. An increasing trend in retreading truck, bus, construction/agriculture machinery, and aviation tires and a decreasing trend in automobile tires is observed. Reduction in scrap tire generation can be encouraged by various measures, including regulatory requirements and economic incentives.

- Burying of whole tires is an environmentally undesirable option and a waste of natural resources, and should be discouraged either by law or by high disposal fee.
- Processed scrap tires (cut, sliced, or shredded) are easy to handle/transport and occupy smaller landfill space. Scrap tires which cannot be recycled currently may be stored in monofills or installations in such a manner that they have no adverse impacts on environments, until development of technology in the future that may convert scrap tires into a high value product.
- The present technologies to reclaim rubber or separate tires into ingredients do not yield products that can compete, in terms of price or quality, with the similar products in the market. Further research is required to develop technologies for reclaiming high quality crumb rubber for reuse in manufacturing new tires and other

rubber products.

- The potential areas for recycling tires in highways are identified in Figure 2.1. Three applications of waste tires and their products hold significant potential for future projection: use of CRA in asphalt pavements; use of shredded tires as lightweight fill; and use of tires and its products for soil reinforcement. The use of asphalt-rubber as crack/joint sealants and SAM's may be further projected since the products have generally performed satisfactorily and are also found cost effective on a life cycle cost basis. Technical, economic, and environmental issues concerning asphalt-rubber and rubber modified asphalt mixtures need to be addressed prior to their extensive use in the pavements (also see Kaya, 1992). The use of tires in subgrade/embankment have been tried in the field successfully and found beneficial as it can consume large quantities of locally available tires (Bosscher et al., 1992; Caltrans, 1986; 1988; Edil, et al., 1990; Lamb, 1992; Mn/DOT, 1990; MPCA, 1990, Read, 1991; and Read, et al., 1991). However, information concerning engineering properties, testing procedures, and design aspects of rubber-soils are severely lacking.
- Non-highway applications which can potentially consume large quantities of waste tires are: breakwaters, artificial reefs, and reclaiming of rubber/other

ingredients. A review of available technologies and markets suggest that these applications are not commercially beneficial at this point in time.

It is evident that waste tire problem in the United States is of great magnitude and has far reaching environmental and economic implications. It is found, based on a critical analysis of the available options for reuse, recycling, and disposal of scrap tires that no single option can solve this problem. A comprehensive strategy is required to combat this problem at government, industry, and public levels. Federal, state and local officials need to integrate their efforts to muster support of the nation to solve this problem. A five point approach is recommended:

(1) Develop and implement comprehensive laws governing manufacture, discards, disposal, storage, incineration, reuse, and recycling of tires.

(2) Take measures to reduce the number of scrap tires generated (i.e., source reduction by having longer wearing tires, reuse, retreading) which may include: regulatory requirements, economic incentives, etc.

(3) Promote use of scrap tires and their components in highway and non-highway applications which hold great promise for consuming large quantities of tires in an environmentally acceptable manner, at significant economic benefits. Three potential areas are identified

in each sector for further projection: in highways - CRA in asphalt paving products, shredded tires as lightweight fill, and tires and its products for soil reinforcement; in non-highway applications - breakwaters, artificial reefs, and reclaiming products through chemical decomposition of tires.

(4) Permit storage of processed tires (i.e., shredded, sliced, or chopped) which cannot be recycled currently, in safe installations/monofills where they have no adverse environmental impacts, for use in the future when technological advances can convert processed tires into high value products.

(5) Allow incineration of tires only in those tire-to-energy facilities which can burn tires or tdf efficiently, while complying with all the emission control regulations.

SECTION 3

SHREDDED TIRES AS LIGHTWEIGHT GEOMATERIAL

3.1 Introduction

Both the stability and settlement of embankments on soft foundations can be improved by use of lightweight embankment fill (Moore, 1966 and Holtz, 1989). Lightweight materials that have been used successfully in highway embankments include bark, sawdust, dried peat, fly ash, slags, cinders, cellular concrete, expanded clay or shale, expanded polystyrene, and oyster and clam shells (Holtz, et al., 1990). Engineers and researchers are constantly endeavoring to develop civil engineering materials that are more durable, more economical, and are lighter in weight to replace conventional materials in order to enhance the stability of slopes/foundations and reduce settlements in problem areas. Certain field and laboratory studies have indicated that these apparently contradictory requirements can be potentially reconciled by the use of rubber-soil.

Rubber tires are available in abundance and their utilization will have a very positive impact on environments. Tires possess some useful properties and have been used in a variety of engineering applications. This section investigates the feasibility of using rubber tires as lightweight geomaterial in highway construction. The section contains: an overview of lightweight materials commonly used for highway embankment fills and other engineering structures; physical and chemical characteristics of tires; and salient aspects of field and laboratory studies in the use of shredded tires as a lightweight fill material. In addition, the section contains a brief discussion on performance, potential environmental impact and constructional aspects of shredded tire embankments. Finally, a summary of relevant conclusions are presented.

3.2 Conventional Lightweight Materials

Table 3.1 lists different types of lightweight materials and their salient properties. All have been used in the past, although some materials are more popular than others and some have been only used on an experimental basis or for structures other than highway embankments. The performance and cost differences between the various materials are significant. However, all have compacted densities significantly less than the unit weights of soils commonly used in embankment construction. Hence their use can substantially reduce the effective weight of embankment. A questionnaire survey by Holtz (1989) indicated that lightweight fill has been used to some extent by 40% of the United States highway agencies responding to the questionnaire.

Lightweight materials are usually expensive, especially if

Table 3.1: Lightweight Embankment Fill Materials (Adapted from Holtz, 1989; Hartlen, 1985; OECD, 1979; Merdes, 1992; Elastizell, 1992; and other sources)

Material	Unit Weight (pcf)	Comments
Bark (Pine & Fir)	35-64	Waste material used relatively rarely as it is difficult to compact. The risk of leached water from the bark polluting groundwater can be reduced or eliminated by using material initially stored in water and then allowed to air dry for some months. The compacted/loose volume ratio is on the order of 50 percent. Long-term settlement of bark fill may amount to 10% of compacted thickness.
Sawdust (Pine & Fir)	50-64	Waste material usually used below permanent groundwater level but has occasionally been employed for embankments that have had the side slopes sealed by asphalt or geomembrane.
Peat: Air dried: milled Baled Horticultural Compressed Bales	 19-32 13 51-64	Proved particularly useful in Ireland for repairing existing roads by replacing gravel fills with baled peat.
Fuel ash, slag, cinders, etc.	64-100	Waste materials such as pulverized fuel ash (PFA) are generally placed at least 0.3 m above maximum flood level. Such materials may have cementing properties producing a significant increase in safety factor with time. In some cases (e.g., furnace slag), the materials may absorb water with time, resulting in an increase in density.
Scrap cellular concrete	64	Significant volume decrease results when the material is compacted. Excessive compaction reduces the material to a powder.
Expanded Clay or shale (lightweight aggregate)	20-64	The physical properties of this material, such as density, resistance, and compressibility, are generally very good for use as a lightweight fill, although some variations may be produced by the different manufacturing processes. The material is relatively expensive but can prove economical in comparison with other techniques for constructing high standard roads. In case this material is used in embankments, a minimum of 20 in. depth of soil cover is required on the slopes and minimum thickness of road base is 2 ft.
Shell (oyster, clam, etc.	70	Commercially mined or dredged shells available mainly off Gulf and Atlantic coasts. Sizes 0.5 to 13 in. (12 to 75 mm). When loosely dumped, shells have a low density and high bearing capacity because of interlock (Mitchell, 1970).

Expanded polystyrene	1.3-6	This is a superlight material used in Norway, Sweden, the United States, and Canada up to the present, but where its performance has proved very satisfactory and its usage is increasing. The thickness of the cover varies between 0.5 and 1 m, depending on traffic loading conditions. The material is very expensive, but the very low density may make it economical in certain circumstances.
Neutralysis	108-115	Neutralysis is a process that integrates materials recovery, waste conservation, and lightweight aggregate manufacturing. The manufacturing process combines non-recyclable solid and liquid wastes fraction of the total non-hazardous waste stream with clay or shale to produce a pelletized feed stock which is then pyro-processed in a series of rotary kilns in which the waste is utilized as fuel. Merdes (1992) reports that the process produces an inert, high quality, lightweight ceramic aggregate ready for use in structural concrete, masonry block manufacturing, and other applications for high quality lightweight aggregate. The aggregate meets ASTM compressive strength requirements (ASTM C330-87). The process is patented by Neutralysis Industries Development Company (NIDC) Northfield, Illinois. The company is currently planning to site a Neutralysis plant in Northwest Indiana and will sell the aggregate for $25 per ton at the plant (Merdes, 1992a).
Low-density cellular concrete, Elastizell:		This is a lightweight fill material manufactured from portland cement, water, and a foaming agent with the trade name "Elastizell EF" and is produced by Elastizell Corporation of America, Ann Arbor, Michigan. Six different categories of engineered fill are produced, i.e., Class I to VI, which have compressive strength 10, 40, 80, 120, 160, and 300 pcf, respectively. Whereas ultimately bearing capacity of Class I-IV is reported as 0.7, 2.9, 5.8, 8.6, 11.5, and 21.6 tsf, respectively. The material is cast in situ and has been used as lightweight fills in a variety of geotechnical applications, such as highway embankments, bridge approaches, foundations, etc. (Elastizell, 1992).
Class I	24	
Class II	30	
Class III	36	
Class IV	42	
Class V	50	
Class VI	80	
Tire chips	20-45	Shredded tires as a lightweight material has been experimented with by a number of states. The benefits include: reduced weight of fill, a free draining medium; inexpensive; and recycling of tires. Potential problems include: leachate of metals and hydrocarbons; high compressibility; and fire risk. Recommended in unsaturated zones of embankment until long term environmental monitoring confirm no likelihood of adverse effects of leachates on groundwater. Need to have a soil cover on top and sideslopes for safety against fire and also provide adequate confinement. Settlements can be reduced by using a thick soil cap and rubber-soil mix instead of chips alone (Author).

they are manufactured (e.g., expanded shales and clays, polystyrene, lightweight concrete, etc.). Typically, costs range from $50 up to $100 per cubic yard, including transportation (Holtz, 1989). Some waste materials (i.e., sawdust, bark, shells, cinders, slags and ashes, etc.) are almost free at the source and only need to be transported to the site. Thus their cost will depend on the distance between the source of waste material and the site. Lightweight fills have also been reportedly found cost effective alternatives in certain applications in the field of geotechnical engineering (Childs, et al., 1983).

Expanded shale lightweight aggregate has been used by the construction industry for many decades to produce lightweight structural concrete and lightweight concrete masonry units (Stoll and Holm, 1985). The aggregate is expanded by heating shale in a rotary kiln under carefully controlled conditions at high temperatures (2100°F). The expanded, vitrified mass that results from this process is then screened to produce the desired gradation for a particular application. NCHRP (1971) reported that some expanded shale has poor freezing resistance and must be kept dry.

Stoll and Holm, (1985) conducted large scale triaxial compression tests on specimens of lightweight expanded shales from five different locations in the United States and also performed uniaxial strain tests (consolidation tests) on aggregate from one of the sites. Their results indicated that the response under triaxial loading was similar to that of many ordinary coarse fill materials; the principal difference is that the lightweight aggregates weigh roughly half as much as conventional materials. Thus the lightweight aggregates may prove to be useful substitutes for ordinary fill materials when the combination of low weight and substantial shear strength warrant the increased cost. The mechanical properties of the aggregate tend to vary somewhat from source to source, so they should be verified in each instances. NCHRP (1971) states that expanded shale seems to be a favorite lightweight fill material because of its more certain behavior.

Nelson and Allen (1974) reported a successful landslide correction using bark and sawdust in a sidehill embankment. They used a 12 inch gravel base under the pavement section; in addition, an asphalt seal was placed on the exposed slope to retard deterioration and pollution. There have been many other projects that used sawdust and bark as lightweight fill in the Pacific Northwest. Large quantities of sawdust was used in the approach embankments to the Dumbarton Bridge in San Francisco (Holtz, 1989). Edil (1983) reported the use of sawdust, wood chips, and expanded shale in the lower portion of surcharge fills on peat. The lightweight part of the fill was left in place after the surcharge was removed.

Hardcastle and Howard (1991) reported the results of a laboratory study on properties of wood fibers used as lightweight fill in embankments for runways and aprons of Benewah County airport (located near St. Maries, Idaho). The various reported properties of wood fiber are: submerged, dry, and wet unit weights as 5, 14, and 55 pcf, respectively; and Φ at 5% and 20% strains as 10° and 30°, respectively. The measured settlement after 32 months of 8 ft. embankment ranged from 0.07 to 0.53 ft, which was twice the predicted value. Cox (1985) reported the coefficient of compressibility for isotropic stress increases of 0.01 to 0.02 per psi for wood chips.

Expanded polystyrene (EPS) is considered a superlight material, because it is about 100 times lighter than ordinary fill materials (unit weight as low as 1.25 pcf; Frydenlund and Aaboe, 1988). The material is available in blocks and can be made sufficiently strong to be able to support ordinary highway pavement and traffic loads with tolerable settlements. But it is also an excellent insulator, and there has been some hesitancy among highway departments in the Northern United States to use it within 4 ft. of the pavement surface because of potential differential icing problems. Other problems with EPS include reports of burrowing animals in the material and increases in unit weight because of water absorption (Holtz, 1989).

Conversely, experience with EPS in a number of countries has been very positive. Frydenlund and Aaboe (1988) reports that more than 100 road projects involving the use of expanded polystyrene

(EPS) have been successfully completed in Norway with volumes varying from a few hundred to several thousand cubic meters of EPS. Applications include embankments on soft and highly compressible soils, behind bridge abutments, construction of sidehill embankments on unstable slopes and for rapid construction of pedestrian underpasses. In Sweden, more than 20 road embankments have been constructed with EPS (Hartlen, 1985). To prevent the EPS from being dissolved by petrol or other chemicals in case of a spill from an overturned tanker on the road, a 4 to 6 in. reinforced concrete slab is cast on top of the EPS blocks. The concrete slab also contributes to the strength of the pavement structure and reduces the total thickness of pavement material above the EPS blocks. EPS does not decay. The material is not fire resistance, and need to be properly encapsuled in soil/ concrete (Frydenlund and Aaboe, 1988).

3.3 Tire Characteristics

Although automobile and truck tires manufactured today are primarily steel-belted radial ply type, other types of tires are available. Some tires are made with fiberglass, Aramid, and/or Rayon. Table 3.2 lists different types of tires and their properties. Most modern tires have a complex composition of natural and synthetic rubbers, chemicals, minerals, and metals. Steel-belted radial ply tires may also contain polyester, steel, or nylon cords. Some radial tires have a fine carcass wire, whereas

Table 3.2: Analysis of Various Tires (After OAQDA, 1991)

TIRE TYPE	SOURCE	ENERGY CONTENT (BTU/LB)	COMPONENTS, PERCENT BY WEIGHT						
			MOISTURE	ASH	SULFUR	CARBON	HYDROGEN	NITROGEN	OXYGEN
FIBERGLASS	POPE, 1991	13,974	0.00	11.70	1.29	75.80	6.62	0.20	4.39
STEEL-BELTED	POPE, 1991	11,478	0.00	25.20	0.91	64.20	5.00	0.10	4.40
NYLON	POPE, 1991	14,908	0.00	7.20	1.51	78.90	6.97	< 0.10	5.42
POLYESTER	POPE, 1991	14,752	0.00	6.50	1.20	83.50	7.08	< 0.10	1.72
KEVLAR-BELTED	POPE, 1991	16,870	0.00	2.50	1.49	86.50	7.35	< 0.10	2.11
UNSPECIFIED TIRE	HALEY, 1984	16,146	0.00	1.50	1.80	89.20	7.30	0.20	NR
UNSPECIFIED TIRE	RYAN, 1989	15,550	0.50	5.70	1.20	83.20	7.10	0.30	2.50

NR - NOT REPORTED

bias ply tires do not. Both radial and bias ply tires contain bead wire, which consists of numerous strands of high tensile strength steel. In the past, both automobile and truck ties have been either radial or bias ply type. Some bias ply tires are still manufactured in the United States, but they are primarily truck tires. About one-half of the truck tires present in the market today are radial and one-half are bias ply types (OAQDA, 1991).

The main constituents of rubber in tires are carbon and oil (hydrocarbons), hence the combustible nature of tires. When tires burn in uncontrolled environments, the black smoke that escapes contains fine particles of carbon. Carbon and hydrogen can make up as much as 96.5 percent of the tire. However, the percentage of ash can be as high as 25%, especially if rubber contains steel (Granger and Clark, 1991; reported by OAQDA, 1991). Although, tires contains a significant amount of sulfur, they are comparatively lower in sulfur than oil and U.S. coal (except low-sulfur coal). The ash resulting from burning coal or TDF (tire-derived fuel) contains metals. Zinc is the main constituent in TDF fly ash, but lead, arsenic, chromium, and cadmium are also present (Granger and Clark, 1991).

Ohio Edison Company conducted a testing program, in May 1990, to determine the feasibility of co-firing whole waste tires and pulverized coal in their plant in Toronto, Ohio (Gillen, 1991). They conducted three test runs daily for each of the five operating conditions, i.e., 0%, 5%, 10%, 15%, and 20% total BTU input to the boiler provided by tires. During five-day tire burn test, three fly ash and one bottom ash samples were collected daily. The samples were analyzed by Wadsworth/Alert Laboratories, Incorporated of North Canton for RCRA heavy metals using the USEPA Toxic Characteristic Leachate Procedure (TCLP). Gillen (1991) reported that all TCLP leachate results for fly ash from the tire burn test were below hazardous waste limits of 100 times the drinking water standards. In addition, all TCLP leachate results for fly ash from the tire burn test were below Ohio solid waste limits of 30 times the drinking water standards, while 72 of these 120 test results passed drinking water standards for heavy metals. For bottom ash from the tire burn test, all leachate results were below drinking water standards for heavy metals.

Rubber tires are designed to withstand the rigors of the environment so that they will have a reasonable useful life on vehicles. Therefore, it is not surprising that discarded tires persist for longer periods. Indeed, it has been estimated that a whole tire requires at least a hundred years to decompose fully (Hofmann, 1974; reported by Cadle and Williams, 1980). The US Army has performed extensive tests of filled rubber vulcanizates to determine the effects of environmental aging on their physical properties (Bergstrom, 1977). It has been reported that styrene-butadiene rubber, the major tire tread vulcanizate, required several years of environmental exposure to show measurable changes in tensile strength or elongation. However, polybutadiene rubber, also a tire-tread component, aged much faster.

Several factors, such as heat, oxygen, ozone, light, humidity, and microorganisms, effect the degradation process (Cadle and Williams, 1980). Selective studies have been made on some of these factors. Cadle and Williams (1980) have reported a study on the environmental degradation of tire-wear particles. They collected soil samples from the roadside. The samples contained different amounts of rubber particles worn from automobile tires. These samples were subjected to different environmental conditions and degradation processes to analyze the effects of various factors on the degradation of rubber particles. The conclusions of their study cannot be applied directly to the degradation of rubber chips used in engineering structures, e.g., embankments, slides areas, etc., where they are not exposed to direct sunlight or other adverse environmental conditions. However, it can be inferred that the protection of rubber chips from severe environmental conditions will further reduce the very slow rate of their degradation.

3.4 Use of Shredded Tires as Lightweight Fill

3.4.1 Field Experience

Various agencies, in the United States and abroad, have evaluated the use of shredded tires as a lightweight material in embankment construction and also for enhancing the stability of slopes in slide areas. A questionnaire survey conducted by the author (Ahmed, 1991) indicated that of the 44 state highway agencies, responding to the questionnaire, four states have experimented with the use of shredded tires in embankments as a lightweight material. These are Minnesota, Oregon, Vermont, and Wisconsin. The experience of each state is described in some detail in the succeeding paragraphs.

Minnesota

The Minnesota Pollution Control Agency (MPCA) has documented over 23 sites (through Feb, 1992) throughout the state which have used over 80,000 cubic yard of shredded tires (about 2.2 million tires). Over half of these projects are privately owned driveways and roads, 4 are city and township roads, 3 are county roads, and 2 are DNR Forest roads. A few of the projects used shredded tires for purposes other than in road fills. One project in downtown Minneapolis used the lightweight tire shreds as a fill material to support a park and landscaping above an underground parking lot. At another site, tire chips were used as lightweight fill over an existing watermain (Lamb, 1992). Six case studies (documented by the Minnesota DOT in a recent report) are described in succeeding paragraphs (location and cross sections are given in Figures 1 and 2), portions of which are excerpted from Lamb (1992).

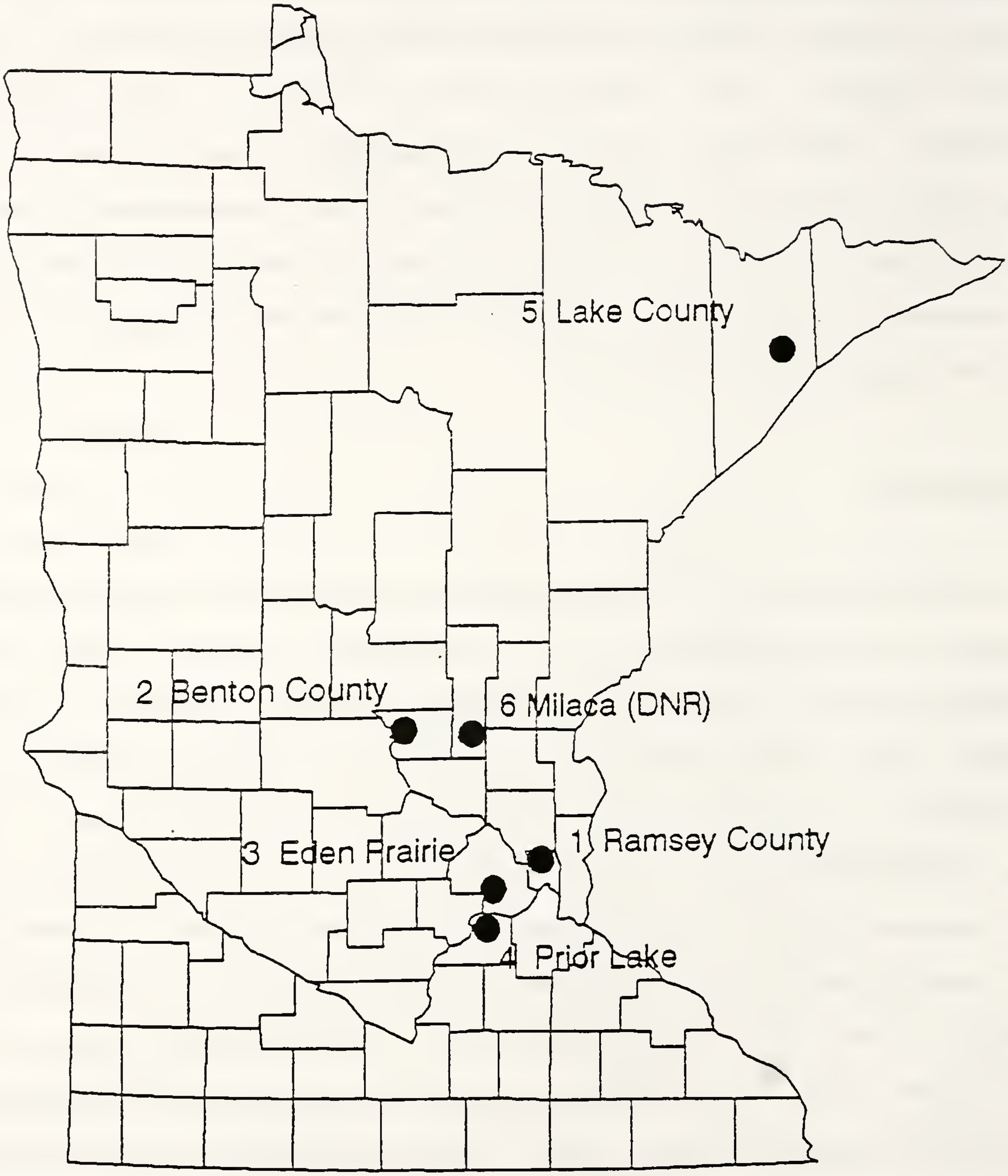

Figure 3.1: Location of Case Studies (from Lamb, 1992).

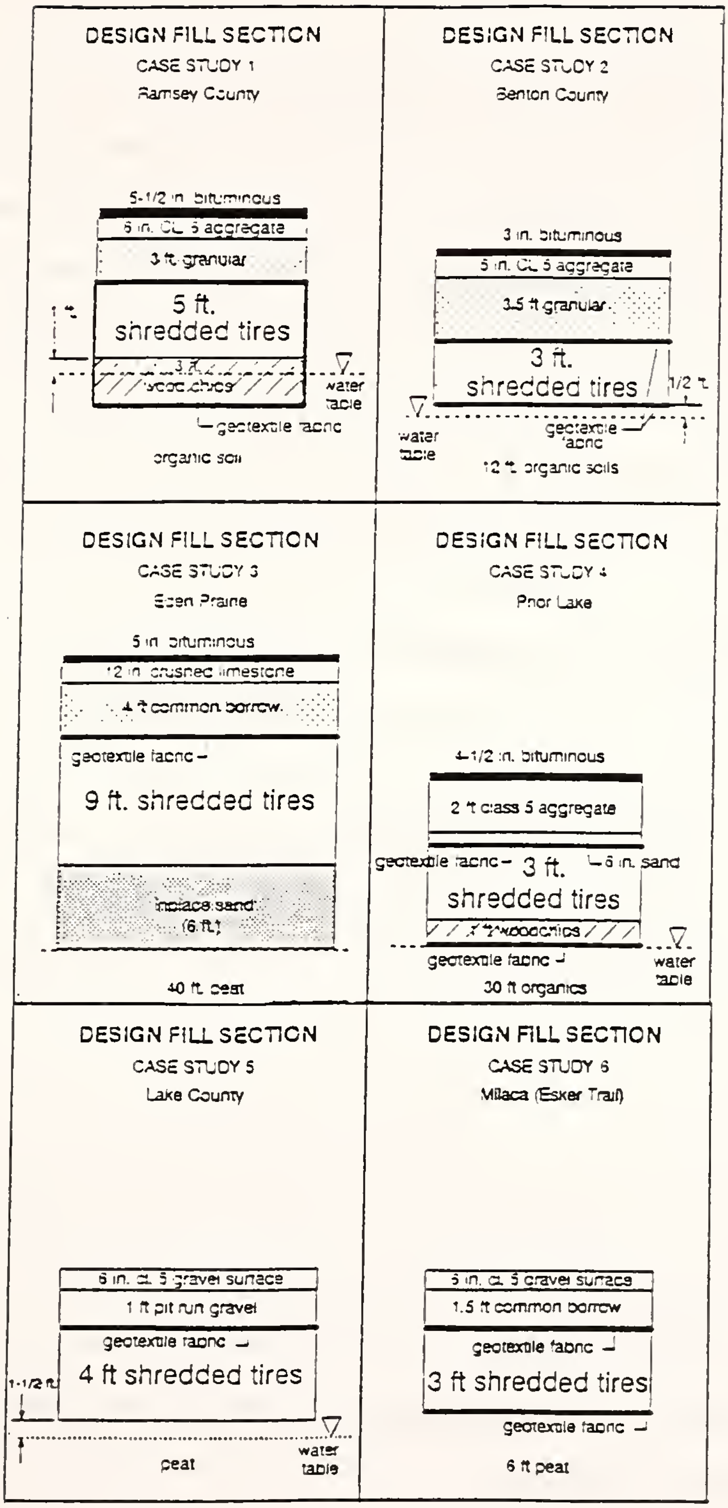

Figure 3.2: Cross Sections of Case Studies 1 to 6 (from Lamb, 1992).

Case Study 1: Ramsey County, Minnesota

A stretch of roadway on Ramsey County Road 59 (near St. Paul, Minnesota), which passes over a mucky low lying area with high water table, experienced excessive settlements and in 1990 required reconstruction. An economic and engineering analysis, conducted by TKDA (a consulting engineering firm) and Twin City Testing Corporation (the geotechnical subconsultant), resulted in the selection of shredded waste tires as the design fill material.

The construction commenced in the winter of 1990. The existing material was excavated to a depth of five feet. A geotextile fabric was placed at the bottom and sides of the excavation. Next, wood chips were deposited to a depth of one foot above the water table. About 4,725 cubic yards of shredded tires were then placed on top of wood chips and compacted to a depth of three feet above the original roadway elevation. The 3x3 inch tire shreds were compacted with a dozer. The top layer of geotextiles fabric was then added and sewn to the initial layer of fabric in order to encapsulate the wood chips and tires. A 3 foot layer of granular material, 6 inches base layer, and 5.5 inches of bituminous base and wearing course were placed on shredded tires fill (see Figure 3.2). The post-construction performance has not yet been reported (Lamb, 1992).

Case Study 2: Benton County, Minnesota

In this case, scrap shredded tires were used as roadway fill

across a swamp that is underlain with peat and muck (Mn/DOT, 1990; and Public Works, 1990). The fill is located on County State Aid Highway 21 north of Rice, Minnesota, which is on US 10 in the north-west corner of Benton County. The original construction across the swamp was stable, but subsequent additions to raise the roadway above the rising water in the swamp overloaded the underlying peat and muck and caused an embankment failure.
The county hired a consultant (Braun Engineering Testing) to review options to correct the soil stability problem. After performing a cost/benefit analysis, it was recommended to use shredded tires as a lightweight fill material.

The construction began in fall of 1989. The county excavated the embankment at the distressed portion, installed a geofabric, and then placed shredded tires directly on the fabric in 2-foot lifts to a height within 3.5 feet of the top of subgrade elevation. After the tires were compacted, an additional layer of fabric was installed on top of the tires, prior to placing granular backfill. The tire fill supports: about 3.5 feet of clean granular soil cap, a conventional gravel subbase and base, and bituminous surfacing. The compacted shredded tire density is reported as 550 lb/cu yard. About 52,000 tires were used in the 250 foot portion of distressed roadway. Some of the construction specifications included (Public Works, 1990):

- The largest allowable piece was about 8 inch square or round, and the longest piece allowed was 12 inch long, whichever was less.

- It was required that chips be free from any contaminants such as oil, grease, etc., that could leach into groundwater.
- Metal fragments were required to be firmly attached and 98% embedded in the tire sections.
- All pieces must have at least one sidewall severed from the face of the tire.

To date (April 28, 1992), this road has not experienced any significant settlements and the bituminous surface is performing satisfactorily (Lamb, 1992).

Case Study 3: Eden Prairie, Minnesota

In Eden Prairie, Minnesota (near Minneapolis) a road embankment project incorporated shredded tires in order to solve a settlement problem (Lamb, 1992). The original fill, placed over a swamp containing 40 ft. of soft organic soils, failed during construction. Three years after the fill, the roadbed was still settling an average of one foot per year. It was decided to use shredded tires as lightweight fill to correct subsidence problem. The original fill was excavated to a depth of 10-14 ft and about 4,100 cu yards of shredded tires were then placed in 2-3 ft lifts. The tire shreds were 6-8 inches wide and 12-24 inches long and were compacted by a D-8 dozer to a density of 40-45 pcf. A geotextile fabric was placed on top of the tire shreds and 4 ft layer of common borrow was then placed on the fabric. After 3 weeks, 12 inches of crushed limestone was graded over the fill material followed by 3.5 inches of bituminous base course. The wearing course was paved the ensuing spring.

Settlement data, obtained from the settlement plates placed both at the bottom and top of the shredded tires, indicate that the fill has performed very well. Over a period of 19 months, the roadway settled an average of 0.9 inches a year, while the subcut (at the bottom of the tires) settled only an average of 0.4 inches per year (Lamb, 1992).

Case Study 4: Prior Lake, Minnesota

In Prior Lake, Minnesota (suburb of Minneapolis) the new alignment of the intersection of Duluth and Tower Avenues passed over a wetland area with 30 ft. of organic deposits. After analyzing various construction options, it was found beneficial to use shredded tires as a lightweight fill material. A geotextile fabric was placed over the wetland and then wood chips were compacted to an elevation of one foot above the expected water table level. Approximately three ft of shredded tires (about 9.600 cubic yards) were then graded over the wood chips. The 4 inch tire shreds were easily graded and compacted with dozers and loaders. The tire fill was covered with a 3 ft. of granular fill and base layer. A plate load test (applied directly on top of the shredded tires) indicated that the tire material was very compressible and displayed a very low modulus (Lamb, 1992).

Case Study 5: Lake County, Minnesota

The Lake County Highway Department reconstructed a gravel road using about 3,900 cubic yards of shredded tires on County State Aid Highway #7, near Finland, Minnesota. The original section, built over peat, experienced excessive settlements. After considering the various options, the county decided to construct the road using shredded tires as lightweight fill material. The road was constructed over the existing grade with a 4 ft layer of shredded tires, capped with a layer of geotextile fabric, followed by about 1.5 ft of gravel. The tire shreds were quite large, ranging in size from 4x12 in. to 1/4 th of a whole tire, and were compacted with a dozer. After two years, the county reports no noticeable settlement of the road section containing tires chips (Lamb, 1992).

Case Study 6: Milaca, Minnesota

The Minnesota Department of Natural Resources reported the use of shredded tires as lightweight fill on a 200 ft section of gravel road. The road, known as Esker Trail, passed over a section of wetland containing unstable peaty soil. The fill section included a layer of geotextile fabric, followed by 3 ft layer (3,000 cubic yards) of shredded tires, and then topped with a second layer of geotextile fabric. This was followed by 1.5 ft of common borrow, and capped with six inches of gravel. It has been reported that post-construction settlements were 40 to 50% less than were expected from mineral fill (Lamb, 1992).

Oregon Slide Correction Project

Based on successful experience of the Minnesota DOT in the use of shredded tires as a lightweight fill in embankment on weak foundation soil, the Oregon DOT also used shredded tires in a slide area on Highway U.S. 42 (Oregon State Route #35, Coos Bay-Roseburg), approximately 25 miles west of Roseburg, Oregon. The slide occurred in a newly-constructed 15 feet high embankment, with slide block extending 150 feet beyond the toe of the embankment to a small creek running parallel to the highway. Succeeding paragraphs of this subsection describe the design, construction, and performance aspects of slide correction at this site by the Oregon DOT, portions of which have been excerpted from Read (1991) and Read, et al. (1991).

Geotechnical analysis suggested reduction of embankment weight and construction of a counterbalance berm between the embankment toe and the creek. The design called for replacement of the existing fill with shredded tires to reduce the weight of embankment. The actual construction involved replacement of 12,800 cu yard of existing soil with 5,800 tons of shredded tires (an estimated 580,000 tires). A drainage blanket consisting of 12 inches of free-draining rock between two layers of geotextile was placed beneath the shredded tire embankment and the berm in order to prevent the groundwater table from rising into the embankment. Three 10-foot-deep French drains were located beneath the blanket to enhance the subsurface drainage. The drainage blanket was required to prevent submergence of tire chips in water.

The embankment construction was completed in two stages to allow traffic on one half of the embankment while the other half was under construction. The shredded tires were brought to the project area from four different vendors, located 150 to 250 miles from the project, using 28 tons "live-bottom" trailers. Dump trucks were employed to deliver the chips to the construction site. A D-8 Dozer was used to spread and compact the chips. The shredded tires were placed in 2-3 ft lifts and each lift was compacted with no less than three coverage in each direction of a D-8 Dozer, achieving in-place density of 45 pcf. The reported density range of loose chips in haul trailers varied from 24 to 33 pcf, depending on the haulage distance and size of the chips. Post construction density under 3 feet of soil, 23 inches of aggregate base, and 6 inches of asphalt and after 3 months under traffic (ATD of 3750 with 20% trucks) was 52 pcf.

The shredded tire fill was constructed to an elevation 12 inch above the design height to compensate for a 10% anticipated compression (the settlement estimates were based on in-situ performance of a tire chips embankment constructed in Minnesota; see Geisler, et al., 1989). It was observed that the thickest portion of the shredded-tire fill (approximately 12.5 feet) compressed 13.4% during construction as follows:

- 16 inches during placement of 3 feet of soil cap.
- 2 inches during placement of 23 inches of aggregate base.
- 2 inches during 3 months of traffic and placement of 6 inches of asphalt concrete.

Deflection testing was conducted using ODOT's Falling Weight Deflectometer (FWD). The average deflection of the pavement over the rubber tire fill was approximately 0.020 inch compared to a typical deflection of 0.010 inch normally measured for a similar asphalt- and -aggregate-base pavement constructed over a conventional soil subgrade. It is expected that, since the increase in dynamic deflection is apparently due to a deep layer (the tires), the deflection increase may have a larger radius and cause less stress in the pavement than similar magnitudes of dynamic deflection with conventional embankment underlying the pavement. The pavement has been heavily instrumented with slope inclinometers, settlement plates, and survey monuments. These devices are reportedly being monitored at regular intervals to determine the performance of the embankment, and the results are expected to be published in the final report.

Read et al. (1991) concluded that embankment construction using waste shredded chips is a viable technology and can consume large quantities of discarded tires at significant engineering benefits. The economics of using shredded tires in embankment depends on many factors, which vary with the local conditions, including: availability of other lightweight materials and their cost; proximately of site to the tire dumps and shredding equipment; and the existence of a state rebate program.

Use of Tire Chips to Cross Boggy Area

The Southeast Chester Refuse Authority in Pennsylvania was confronted with a problem of road construction over soft soil for movement of equipment from landfill to the storage sheds (Biocycle, 1989). They placed an 18 inch layer of tire chips (2x2 inch) along a 525 feet section of roadway passing over boggy area, without compaction or any other treatment. It has been reported that the section containing tire chips drains well and provides a good riding surface.

Test Embankment Containing Shredded Tires

The University of Wisconsin-Madison, in cooperation with the Wisconsin DOT, has conducted a limited field experiment to determine the feasibility of incorporating shredded tires in highway embankment (Edil et al., 1990 and Bosscher, et al., 1992). They constructed a 16 feet wide and 6 feet high test embankment consisting of ten different sections, each 20 feet long, using locally available soil and shredded tires in a number of different ways, including: pure tire chips, tire chips mixed with soil, and tire chips layered with soil. They also varied the embankment configuration for different sections of embankment to determine the optimum slope. A geotextile fabric was placed on all sides of tire chips to serve as a separator between materials of the embankment and the surrounding materials. The embankment was constructed parallel to the access road of a sanitary landfill and exposed to the heavy incoming truck traffic.

The compaction was done using sheepsfoot roller with vibratory capability. The field observation during construction included (Edil, et al., 1990):

- The handling and placement of tire chips were not a problem. The back hoe was found appropriate for spreading the material evenly.
- Tracked equipment could easily maneuver on tire chips.
- Neither vibratory nor static compaction significantly induced compaction in the tire chips. However, non-vibratory compaction was found more appropriate.
- The compacted field density varied from 20 to 35 lb/cu ft, depending upon type/size of chips.

Edil, et al. (1990), based on during construction and initial post construction evaluations, have reported that construction of embankment with tire chips does not present any unusual problems. Leachate characteristics indicated little or no likelihood that shredded tires would effect groundwater. The main problem is reportedly related to control of compressibility. A two-year monitoring and evaluations of the test embankment supports the use of properly confined tire chips as a lightweight fill in highway applications (Bosscher, et al., 1992). Some of the observations include:

- After an initial adjustment period, the overall road performance was similar to most gravel roads.
- The embankment sections having 3 feet soil cap performed better compared to that having 1 foot of soil.
- The mixture of soil and chips performed similar to the pure chip sections with a thicker soil cap. The presence of a thick soil cap reportedly helps reduce plastic deformation.
- Comparatively, the layered section performed the worst.
- The leachate analysis indicated that shredded automobile tires show no likelihood of having adverse effects on groundwater quality.

Use of Tire Chips on a New Interstate in Colorado

The Colorado Department of Transportation has recently experimented with the use of shredded tires as a lightweight fill material (Lamb, 1992). Shredded tires have been used on a 200 ft portion of Colorado's new Interstate 76, a four-lane highway that will connect west Denver to Nebraska when completed in 1993. More than 400,000 tires chips of about four-inch size have been consumed in a 5 ft fill. The tire embankment has been instrumented for monitoring the long term performance of the fill.

Proposed Shredded Tires Test Embankment in North Carolina

The North Carolina Department of Transportation (NCDOT) has initiated a project, with the assistance of Federal Highway Administration (FHWA), to determine feasible usage of recyclable materials for highway construction (Whitmill, 1991). The project consists of widening a two-lane segment of NC 54 in Orange County to a four-lane divided highway for a distance of 2.182 miles. As part of this project, an embankment will be constructed with layers of shredded tires mixed with soil, using approximately 65,000 tires. The proposed embankment design requires:

- Shredded tires may not be placed within three feet of the outside limits of embankment, within four feet of subgrade, or below the water level of the surrounding area.
- The embankment shall be constructed by placing alternate layers of shredded tires and soil and mixing and blending them together during compaction.
- Shredded tires shall constitute between 10% and 40% by volume of that portion of the embankment, achieving an

average of 25 percent.

3.4.2 Laboratory Studies

Various databases, including: Compendex Plus (online form of engineering index); NTIS (National Technical Information Service); TRIS (Transportation Research Information System); Enviroline; and Pollution Abstracts, were searched to locate the literature on the subject. Two laboratory studies were identified: (1) a limited laboratory study conducted by the University of Wisconsin-Madison to determine the mechanical properties of rubber and rubber-till mix, and leachate analysis of specimens collected from shredded tires test embankment (Edil, et al., 1990 and Bosscher, et al., 1992); and (2) the Minnesota laboratory study on leachates from tire and asphalt materials (MPCA, 1990). Both studies are briefly described in succeeding paragraph.

Wisconsin Study

A limited experimental program was carried out at the University of Wisconsin-Madison to develop qualitative information about the compaction and compression behavior of tire chips, and analysis of leachates from a test embankment made of rubber-soil (Edil, et al., 1990). Their experiment involved placement of rubber chips of different sizes alone and mixed with sand in a 6-in. Proctor mold and then applying load using a disk placed on the tire chips. The load-deformation response of rubber chips indicated that the major compression occurs in the first cycle. A portion of this compression is irrecoverable; but there is significant rebound upon unloading. The subsequent cycles tend to be similar with less rebound; however, the rebound is nearly the same from one cycle to another. It is observed that the slope of the recompression/rebound curve is markedly lower beyond a certain vertical load of about 1000 lbs.

Edil, et al. (1990) also conducted some compression tests on rubber-sand mix, varying sand/chip ratios. Their tests on rubber-sand mix yielded compression curves similar to rubber chips alone. However, the maximum compression increased as more and more cycles of loading took place, and the magnitude of the maximum compression was less than about 0.1 inch as compared to about 2 inches for the plain tire chips. Their test results, on specimens of sand/chip ratios varying from 100% sand to 100% chips, indicated that the compression increases significantly when tire chips content were increased beyond 30% by weight of sand.

The writer urges caution in using data reported by Edil, et al. (1990) concerning chips and chip-sand mix, since they conducted tests in a compression mold too small in diameter for the size of chips tested (chip sizes of 1.5 inch and even larger were tested in

6 inch Proctor mold). It is likely that greater side frictions are induced in a compression mold incompatible with the sizes of chips tested, which may have led to measuring incorrect load-deformation response. A careful review of reported data indicates that the reported deformations are significantly lower than are expected under corresponding loads.

Edil et al. (1990) have also reported duplicate EP toxicity and AFS leaching tests performed on tire chip samples by the Wisconsin State Laboratory of Hygiene. The test results indicate that the shredded automobile tire samples show no likelihood of being a hazardous waste. The shredded tires appear to release no base-neutral regulated organics. The tire samples showed detectable, but very low release patterns for all substances and a declining concentrations with continued leaching for most substances. It is suspected that several of these substances may have been released from surface coatings rather than leached from the tire material. Four metallic elements, i.e., barium, ferrous, magnesium, and zinc, exhibited increasing concentrations with continued leaching. The highest concentrations for Fe and Mn were at or above their applicable drinking water standards, while those for Ba and Zn were well below their standards.

Edil et al. (1990) report that by comparison to other wastes for which leach test and environmental monitoring data are available, the tire leach data indicate little or no likelihood of shredded tires effecting groundwater. Bosscher, et al. (1992) have reported that an overall review of the available leach data and results of the recent leach tests on samples collected from two lysimeters, installed during construction of the test embankment in December 1989, support their initial conclusions concerning potential impact of shredded tires embankment on environments, reported by Edil, et al. (1990). Their (Bosscher, et al., 1992) recent evaluations confirm that shredded automobile tires show no likelihood of having adverse effects on ground water quality.

Minnesota Study on Tire Leachates

The Minnesota Pollution Control Agency (MPCA) sponsored a study on the feasibility of using "Waste Tires in Subgrade Road Beds" (MPCA, 1990). Twin City Testing Corporation (TCT) of St. Paul, Minnesota, performed the laboratory study to evaluate the compounds which are produced by the exposure of tires to different leachate environments. They subjected the samples of old tires, new tires, and asphalt to laboratory leachate procedures at different conditions, i.e., at pH 3.5, pH 5.0, approximately neutral pH and 0.9% sodium chloride solution, and pH 8.0. They also conducted field sampling. As a result of elaborate testing and analysis, TCT reached the following conclusions (MPCA, 1990):

- Metals are leached from tire materials in the highest concentrations under acid conditions; constituents of concern are barium, cadmium, chromium, lead, selenium, and zinc.

- Polynuclear Aromatic Hydrocarbons (PAHs) and Total Petroleum Hydrocarbons are leached from tire materials in the highest concentrations under basic conditions.
- Asphalt may leach higher concentrations of contaminants of concern than tire materials under some conditions (see Table 3.3).
- Drinking Water Recommended Allowable Limits (RALs) may be exceeded under "worst-case" conditions for certain parameters.
- Co-disposal limits, EP Toxicity limits, and TCLP criteria are generally not exceeded for the parameters of concern.
- Potential environmental impacts from the use of waste tires can be minimized by placement of tire materials only in the unsaturated zone of the subgrade.

Table 3.3: Comparison of Asphalt and Tires in Leachate Tests (MPCA, 1990)

Asphalt > Tires	Tires > Asphalt
Aluminum	As (detected @ pH 5.0 only)
Barium	Cd (detected @ pH 3.5 & 5.0)
Calcium	Cr (detected @pH 3.5 only)
Magnesium	Pb (detected @ pH 3.5 only)
Sulphur	Zinc
Selenium (@ pH 3.5 only)	Carcinogenic PAHs
Sn	-
Total petroleum hydrocarbons	-
Non-carcinogenic PAHs	-

Tires Chips as Aggregate in Drainage Layers/Channels

A laboratory study was conducted by Bressette (1984) to determine feasibility of using tire chips as an alternate to conventional aggregate in drainage layers/channels. He performed constant head permeability tests on compacted and uncompacted specimens of chopped used tire material (approximately 2-inch squares), shredded tires (100% passing 2-inch sieve), and coarse aggregate (open graded, percent passing sieves 2, 1.5, 1, 3/4, and 1/2 in was 100, 99, 43, 39, and 1%, respectively). The permeability values for the three materials were within the same order of magnitude, i.e., 10^4 ft/day (with only 3 exceptions in 42 tests). All values were in the upper range of permeability values required for subdrainage material. Although the tire chips were found technically feasible as an alternate permeable material, the trends in the availability of used tires by-products in California, at that point in time, did not favor the use of tire chips as a substitute material in a permeable layer/drainage channel.

3.5 Discussion

The preceding subsections present a summary of commonly used lightweight materials, physical and chemical characteristics of tires, and various laboratory and field studies on shredded tires. A review of commonly used lightweight materials (Subsection 3.2 and Table 3.1) indicates significant diversity in their engineering properties. They also widely differ in their relative cost and for their impact on environments. Hence, dry density or any other property alone cannot be a sole criterion for comparison of different lightweight materials. Some materials, especially manufactured, possess very attractive engineering properties, but they also cost more. In certain cases some manufactured materials are not available in large quantities required for highway construction purposes.

Lightweight waste materials, such as sawdust, bark, slags, cinders, and ashes, are generally available in abundance and mostly at no cost at the source. These materials have traditionally been used as lightweight fills by the United States highway agencies and may be rationally compared with another waste, like tire chips. Sawdust and bark have unit weights ranging from 35 to 64 pcf, are biodegradable, difficult to compact, require treatment to prevent groundwater pollution, need to be encapsuled in soil cover, and undergo significant long term settlement (see Table 3.1). Salient properties of slags, cinders, and ashes include: dry unit weights ranging from 64 to 100 pcf; may absorb water, resulting in an increase in density; possess high variability; and leachates may adversely effect groundwater quality or the structures in the vicinity of waste material (Table 3.1; Ahmed, 1991; Huang, 1990).

Rubber tires by the millions are discarded annually in the United States and tire chips are available in abundance. Tires possess high tensile strength, are chemically very stable and practically non-destructible. Field density of shredded tires vary from 20 to 45 pcf, depending on the size of chips, method of compaction, and thickness of compacted layers. No unusual problems have been encountered during field compaction of tire chips. A back hoe is considered suitable for spreading the chips. A D-8 crawler tractor is found appropriate for compaction. The environmental impact studies indicate that shredded tires are not a hazardous material, as the parameters of concern do not generally exceed the EP Toxicity and TCLP criteria (MPCA, 1990; Edil, et. al, 1991; and Bosscher, et al. 1992). However, the Drinking water Recommended Allowable Limits for Minnesota are exceeded under "worst case" conditions (MPCA, 1990).

To minimize the potential adverse effects of leachates from tire chips, MPCA (1990) recommended the use of tire chips only in unsaturated zones. Note that the various parameters of concern leached from the tire chips depend on the environmental conditions prevalent in embankment fill, i.e., pH of permeant and soil. Hence, the worst conditions upon which the conclusions have been based (i.e., extreme pH values) may not exist in a shredded tire embankment. This is confirmed by a recent report by Bosscher et al. (1992), which is based on two-year environmental monitoring and evaluation of leachates from a test embankment incorporating shredded tires. The report states that "...by comparison to other wastes for which test and environmental monitoring data are available, the tire leach data indicate little or no likelihood of shredded tires having adverse effects on groundwater."

A major concern in using tire chips in embankment is the large settlements (about 10 to 15%) observed in various field and laboratory studies (e.g., Geisler, et al, 1989; Edil, et al., 1990; Lamb, 1992; and Read, et al., 1991). Holtz (1989) comments that no research has been reported in the literature on tolerable settlements of highway embankments. NCHRP (1971) has reported that post-construction settlements during economic life of roadway of as much as 1 to 2 ft are generally considered tolerable provided they: (1) are reasonable uniform; (2) do not occur adjacent to a pile-supported structure; and (3) occur slowly over a long period of time. Post-construction settlements of shredded tire embankment can be reduced by: placing a thick soil cap over tires fills, i.e., by increasing confining pressure; and using rubber-soil mix instead of tire chips alone. The detrimental effects of anticipated excessive settlements can be reduced by using tires under flexible pavement only and letting the tire chips settle under traffic before placing the final surface course.

Another concern in using tires in embankment may be the potentially combustible nature of tires. To reduce the possibility of fire, a protective earth cover may be placed on top and side slopes of tire embankments. A similar soil cover is recommended for some other lightweight materials, like wood chips, sawdust, slags, ashes, expanded clay or shale, etc. for protection against fire or to prevent leaching of undesirable materials into groundwater. During construction, normal caution is required to avoid any fire in tires stockpiled on the site or embankment tires that have not yet been capped with soil.

Compacted tire chips (about 2x2 in. nominal size) have permeability values equivalent to typical values for coarse gravel (Bressette, 1984). This property of chips renders them suitable for use in subdrainage as an alternate permeable aggregate. As a highly permeable material, pore pressure developments are prevented in tire fills and backfills. Use of tire chips in alternate layers with non-select fills, like clays, silty clays, etc., will provide a shorter drainage path and thus help accelerate consolidation of the layer.

The use of shredded tires in embankments offers the potential benefit of disposing of large volumes of tires in short sections of highway. For example, the use of an asphalt-rubber pavement overlay utilizes only about 3600 tires per miles of 2-lane road while a mile of 2-lane embankment 20-feet high would utilize about 5 million tires (one tire equals approximately one cubic foot loose bulk density before compaction; Read, et al., 1991).

3.6 Summary and Conclusions

A solution to enhance the stability and reduce the settlement of highway structures on slopes and highly compressible soils is to replace the existing material with a material of lower density and/or use lighter weight fills. This section considers the feasibility of using shredded tires as lightweight fill or backfill material in highway structures. The section contains: a brief review of commonly used lightweight materials; physical and chemical characteristics of rubber tires; and a synthesis of field and laboratory studies on incorporating shredded tires in highway embankments. Finally, it presents a brief discussion on the use of shredded tires in highway structures.

Based on a critical analysis of available information on the use of shredded tires in highway structures and a comparison of rubber chips with traditional lightweight materials, it is concluded that the use of shredded tires in highway construction offers technical, environmental, and economic benefits under certain conditions. The salient benefits of using tire chips as a lightweight geomaterial are: reduced weight of fill - helps increase stability, reduce settlements, and correct or prevent slides on slopes; tire chips serve as a good drainage medium, thus prevent development of pore pressures during loading of fills and can also serve as substitute to conventional permeable materials for subdrainage; reduces backfill pressures on retaining structures; provides separation to prevent the underlying weak/problem soils from mixing with subgrade/base material; helps conserve energy and natural resources; and can consume large quantities of waste tires, which has a very positive impact on the environments.

Potential problems associated with the use of shredded tires in highway embankments include: leachate of metals and hydrocarbons; fire risk; and large compressibility of tire chips. Drinking water Recommended Allowable Limits (RALs) for Minnesota are found to be exceeded under "worst-case" conditions (MPCA, 1990). However, a recent field study reports that shredded automobile tires show no likelihood of having adverse effects on groundwater quality (Bosscher, et al., 1992). Proper soil cover is required on top and sideslopes of shredded tire embankment for safety against fire. During construction, normal caution is required to be observed against fire in the stockpiled tires or in embankment tires that have not yet been capped with soil.

Field studies indicate 10 to 15% settlement of tire embankment under 4 to 6 ft of soil/pavement overburden pressure and average traffic conditions. Potential settlements can be reduced by providing a thicker soil cap and using rubber-soil mix instead of chips alone. Detrimental effects of post-construction settlements can be reduced by using tires under flexible pavements only and letting the chips settle under traffic for some time before laying a final surface course. In addition, information on the use of shredded tires in highway structures is severely lacking, some of the areas of major deficiencies are: lack of requisite data on stress-strain and strength behavior of chips and chip-soil mix for design and prediction of performance of highway structures; long term impact on environments; and potential economic benefits in the use of tire chips in INDOT facilities.

Prior to extensive use of shredded tires in INDOT facilities, the following is recommended to be accomplished to satisfy technical, environmental, and economic concerns. This will also help INDOT to develop bid specifications for incorporating shredded tires in highway structures.

- Determine compactibility of tire chips and chip-soil mix; especially analyze the effects of compaction method, compactive effort, chip sizes, tire chip/soil ratios on the density/compaction behavior of tire chips and tire chip-soil mix.
- Determine stress-strain relationships and strength/compressibility parameters for a rational design of highway structures incorporating shredded tires and prediction of their performance.
- Determine the influence of traffic loading on the behavior of shredded tire fills.
- Synthesize and analyze the data from ongoing laboratory

and field studies on the environmental impact of using shredded tires in highway structures.

- Synthesize information on the ongoing performance monitoring of various shredded tire embankments to develop correlations between field and laboratory data, and also assess long term performance of shredded tire embankments.
- Economic analysis of using shredded tire fills, considering local conditions.

SECTION 4

COMPACTION BEHAVIOR OF RUBBER SOILS

4.1 Introduction

The first phase of this study consisted of determining the compaction behavior of rubber soils. The testing program was formulated to develop quantitative information about the compaction characteristics of the tire chips alone, and also when they are mixed with different soils. The selection of tire chips for this purpose was made considering the capability of laboratory equipment and the type of tire chips which are routinely produced by the various local shredding facilities. The selection of soils for experimental parametric and material behavior studies is always a difficult process, since it requires that soil samples be uniform (e.g., have identical basic index properties such as grain size and Atterberg limits) and also available in large quantities. Natural soils, besides being difficult to procure, rarely meet these requirements.

Careful consideration of various factors, namely: availability of soils, least variability in their properties, and existence of prior data on the soils for comparison led to the conclusion that research objectives set forth for this study could best be accomplished by using manufactured soils and/or prepared natural soils. It was also rationally concluded that two soils, one each from the family of fine grained and coarse grained soils, will be adequate to determine the effects of adding tire chips on the shear and compaction behavior of soils. Keeping these factors in view, Ottawa sand, a manufactured coarse grained soil, and Crosby till, a locally found natural fine grained soil, were selected for this study. Large quantities of both the soils were procured and prepared to obtain homogeneous samples and also achieve the desired gradation.

The subsequent subsections describe the tire chips, test soils, testing equipment, and experimental procedures. The results of compaction tests on rubber soils are presented graphically in Figures 4.2 to 4.6. Finally, the results are critically analyzed to quantify the compaction behavior of rubber-soils. A summary of conclusions is presented at the end of this section.

4.2 Description of Rubber Chips

Rubber tires are cut into small chips using different types of shredding equipment. Shredding systems are basically of two categories: mobile and stationary. The mobile units are usually small and have a lower output. The horsepower of shredding systems varies from about 30 to more than 375, with capacity of 100 to more than 2000 tires per hour (from whole tires to rough shreds). The steel is pulled from the tire chips as the size of chips is reduced. The amount of steel in rubber chips also depends on the state of sharpness of shredder blades. Sharp blades make comparatively cleaner cuts through a shearing process. During shredding operation, the large pieces of steel belt are removed by magnets. The size of chips is governed by the design of a particular machine and the setting of its cutting blades. Small size chips are produced by processing the material many times through the same shredder and/or through more than one shredder. Automatic classifiers are also used which rotate around the shredder cutting chamber and separate finer sizes from coarser ones. The tire chips so produced are of irregular area with the smaller dimension being the size specified by the manufacturer.

The tire chips that are being used for this study were supplied by: ASK Shredders Corporation, East Chicago, Indiana; Baker Rubber, South Bend, Indiana; Rubber Materials Handling, East Chicago, Indiana; and Carthage Machine Company, New York. The samples of tire chips vary in size from sieve No. 4 to 2 inches plus. The rubber chips have generally cleaner cuts and only a small percent of steel wires are exposed. Free steel wires are not present in the rubber chip. A mechanical analysis was performed on tire chip samples collected from the various shredding agencies, the results of which are plotted in Figure 4.1. The grading curves of various chip samples generally indicate a uniform gradation of tire chip samples.

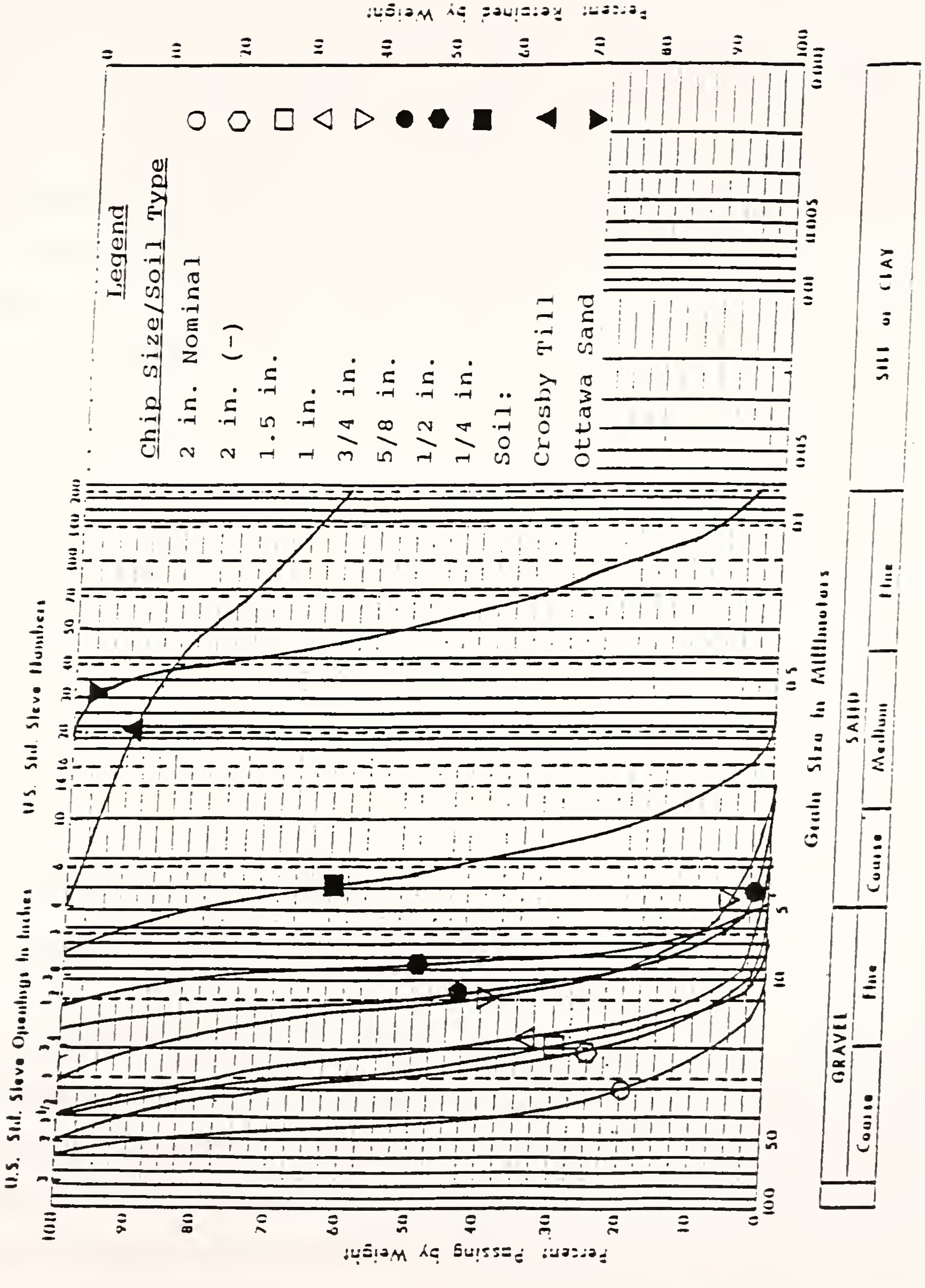

Figure 4.1: Mechanical Analysis of Test Soils and Rubber Chips.

4.3 Test Soils

Crosby till, which is a natural fine grained soil, is being used for this study. The soil was obtained from about 200 m west of the intersection of McCormick and Cherry Lane, West Lafayette, Indiana. The development in Lafayette and its environs provided opportunities of extensive research on this soil at Purdue University, which stimulated interest in understanding its basic behavior. The soil can be conveniently obtained and has been routinely used in many research studies over the years at Purdue University (e.g., Holtz and Kovacs, 1981). The test soil was prepared in the laboratory to eliminate the possibility of spatial variability in the properties of this natural soil and correctly understand the effects of adding rubber chips on the shear and compaction behavior of soil.

Preparation of the test soil included: air drying a large quantity of soil, which was considered sufficient to meet the testing requirements of this study; sieving the natural soil through a US Standard No. 4 sieve to remove gravel particles or organic materials; thoroughly mixing the soil to achieve homogeneity; and storing the soil in sealed containers. Index tests have been performed on the soil samples from various containers and the soil has been found fairly homogeneous, having identical properties. The soil has been classified as CL-ML (sandy silty clay) according to the Unified Soil Classification System

(USCS) and A-4(0) as per the American Association of State Highway and Transportation Officials (AASHTO) classification system. The data obtained through the mechanical analysis of this soil is plotted in Figure 4.1. Some of the engineering properties of this soil are summarized in Table 4.1.

The sand used in this study was manufactured by U.S. Silica, Ottawa, Illinois and is sold under the trade name Ottawa sand. It is white medium to fine sand. The desired gradation was achieved by mixing three different types of Ottawa sands in equal proportions, namely: Flintshot (AFS Range 26-30); #17 Silica (AFS Range 46-50); and F-125 (AFS Range 115-130). The grain size distribution curve of the test soil is plotted in Figure 4.1. The sand is classified as SP (poorly graded sand) according to the USCS and A-3(0) as per the AASHTO classification system. Salient engineering properties of the soil are summarized in Table 4.1.

4.4 Description of Testing Equipment

The compaction tests conducted for this research were performed using a mechanical compactor and an electromagnetic, vertically vibrating table. The mechanical compactor used for this study was developed and manufactured by Soiltest, Inc. The apparatus is equipped with a device to control the height of drop to a free fall of 12 in. or 18 in. (depending upon the setting) above the elevation of the soil, and uniformly distribute such

Table 4.1: Summary of Properties of Soils Used in This Study

Physical Properties	Crosby Till	Ottawa Sand
Liquid Limit (%)	19.8	-
Plastic Limit (%)	15.5	NP
Plasticity Index (%)	4.3	NP
Maximum Dry Density (pcf):	-	-
Modified Proctor	130.25	-
Standard Proctor	124.1	-
Vibration Method	-	118.75
Optimum Water Content (%):	-	-
Modified Proctor	9.3	-
Standard Proctor	10.6	-
Soil Classification:		
Unified Soil Classification	CL-ML (Sandy Silty Clay)	SP (Poorly Graded Sand)
AASHTO Soil Classification	A-4(0)	A-3(0)

drops to the soil surface. The mechanical compactor is designed with a height adjustment for each blow, all subsequent blows have a rammer free fall of 12 in. or 18 in. measured from the elevation of the soil as compacted by the previous blow. When used with the 4-in. mold, the specimen contact face is circular with a diameter of 2.00 in. When used with the 6-in. diameter mold, the specimen contact face has the shape of a section of a circle of a radius equal to 2.90 in. The sector face rammer operates in such a manner that the vertex of the sector is positioned at the center of the specimen. The rammer weighs 5.5 lb. The rammer shaft is hollow inside and can accommodate an additional shaft to increase the rammer weight to 10 lb, if required.

4.5 Experimental Procedures

The compaction tests on Crosby till were performed following procedures described in ASTM D 698 (AASHTO: T99-61) and D 1557 (AASHTO: T180-61). A mechanical rammer and 6-in. diameter mold were used to perform the compaction tests. Three different compactive efforts were used: (1) sample compacted in 5 equal layers with 56 blows/layer of 10-lb hammer with an 18-in drop (i.e., modified Proctor method); (2) sample compacted in 3 equal layers with 56 blows/layer of 5.5-lb hammer with a 12-in. drop (i.e., standard Proctor method); and (3) sample compacted using a procedure similar to standard Proctor with number of blows per layer adjusted to give the compactive effort equivalent to 50% of standard Proctor.

The compaction tests on Ottawa sand were performed using procedures described in ASTM D4253. An electromagnet, vertically vibrating table was used for providing the desired level of vibration. Oven dried sand and rubber-sand mix were placed in 4-in. diameter compaction mold under 2 psi surcharge applied to the surface of the specimen. The dry density was computed after vibrating the specimen for 8 minutes at 60 Hz.

4.6 Laboratory Testing Program

The laboratory testing program was formulated to accomplish the research objectives set forth in Section One. During compaction phase of this study, the samples were compacted using two different methods, i.e., Proctor method of compaction for Crosby till and vibration method for Ottawa sand. In case of Crosby till, the optimum moisture contents were determined for modified and standard compactive efforts. The samples of Crosby till were prepared at the optimum moisture content, then placed in a container, sealed and stored in a humid room for 24 hours prior to testing. The compaction tests were then performed on rubber-soil samples. The variables considered included: compactive effort, size of chips, and the ratio of soil/chips. Three different compactive efforts were used, i.e., modified Proctor, standard Proctor, and 50% of standard Proctor. The tire chips of seven different sizes ranging from sieve No. 4 to 2 inches plus are being investigated in this study. The soil/chip ratios were varied from pure soil to pure chips (i.e., quantity of chips in mix varied from 0 to 100% of dry weight of soil).

In case of Ottawa sand, the soil was oven dried and then compacted using a vibratory table (see ASTM 4253). First, the maximum density of the sand was determined through a number of trials, and then the sand was mixed with rubber chips in different ratios. In the chip/sand mix, the quantity of tire chips was varied from 0 to 100% of dry weight of soil (i.e., from pure sand to pure chips).

In the subsequent phases of this research study, the stress-strain and strength behavior of compacted rubber soils will be determined under static and dynamic loading conditions. A 6-inch diameter triaxial cell and 12-inch diameter compaction/compression mold have been prepared for this purpose. The MTS system will be used to simulate the various static and dynamic field loading conditions. Necessary modifications have been made in the hardware and appropriate computer programs have been installed to acquire the data automatically during the testing.

4.7 Presentation of Test Results

Table 4.1 present the engineering properties of test soils.

Figure 4.1 plots the results of mechanical analysis performed on the tire chips and the test soils. The results of compaction tests on rubber soils have been graphically presented in Figures 4.2 to 4.6. Figures 4.2 and 4.3 plot dry unit weight versus percent of rubber chips for all the compaction tests on rubber-Crosby samples using modified and standard Proctor tests, respectively. Figure 4.4 plots the data from compaction tests on rubber-sand using the vibration method. Figure 4.5 compares the compaction curves on dry density versus percent chips plot for all the tests performed on rubber soils. Figure 4.6 presents the compaction results on tire chips alone using different compaction methods and also varying the compactive efforts.

4.8 Discussion

Figure 4.2 presents the data on maximum dry density versus percent rubber chips plot obtained from modified Proctor compaction tests performed on rubber-Crosby mix. The curve indicates that the density decreases linearly with increase in chips until about 25% of chips, and thereafter the slope of the curve constantly decreases with increase in chips (i.e., the density does not decrease proportionate to increase in percent chips). This trend is followed until about 40% chips by dry weight of soil, and beyond this value any increase in percent rubber chips causes little reduction in the density of rubber-soil. Similar trends are observed when compactive effort is reduced from modified to an

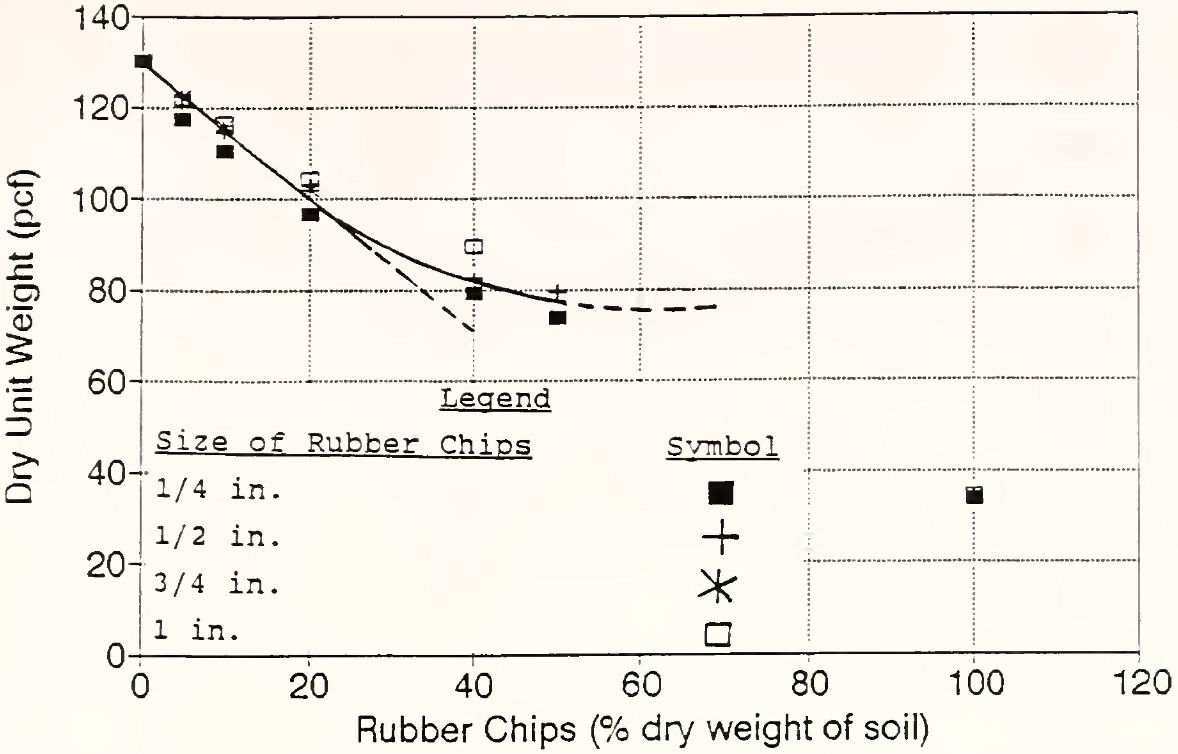

Figure 4.2: Density Versus Percent Chips from Modified Proctor Compaction Tests on Rubber-Crosby Till.

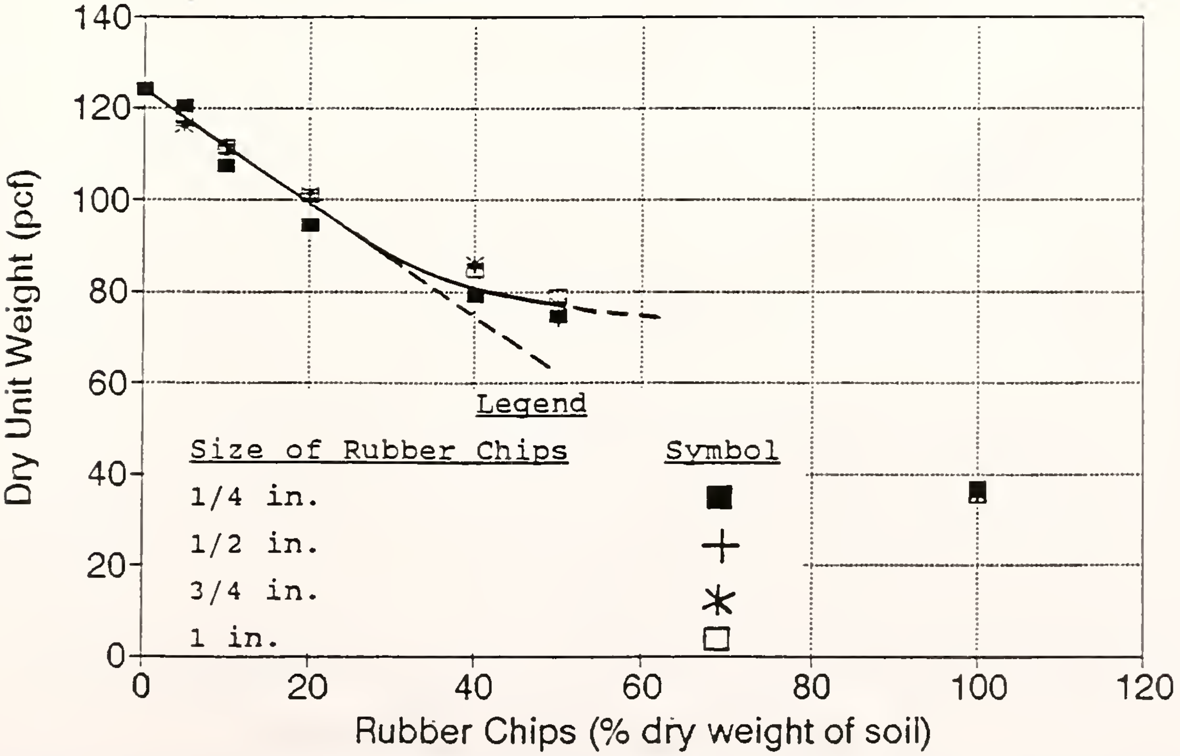

Figure 4.3: Density Versus Percent Chips from Standard Compaction Tests on Rubber-Crosby Till.

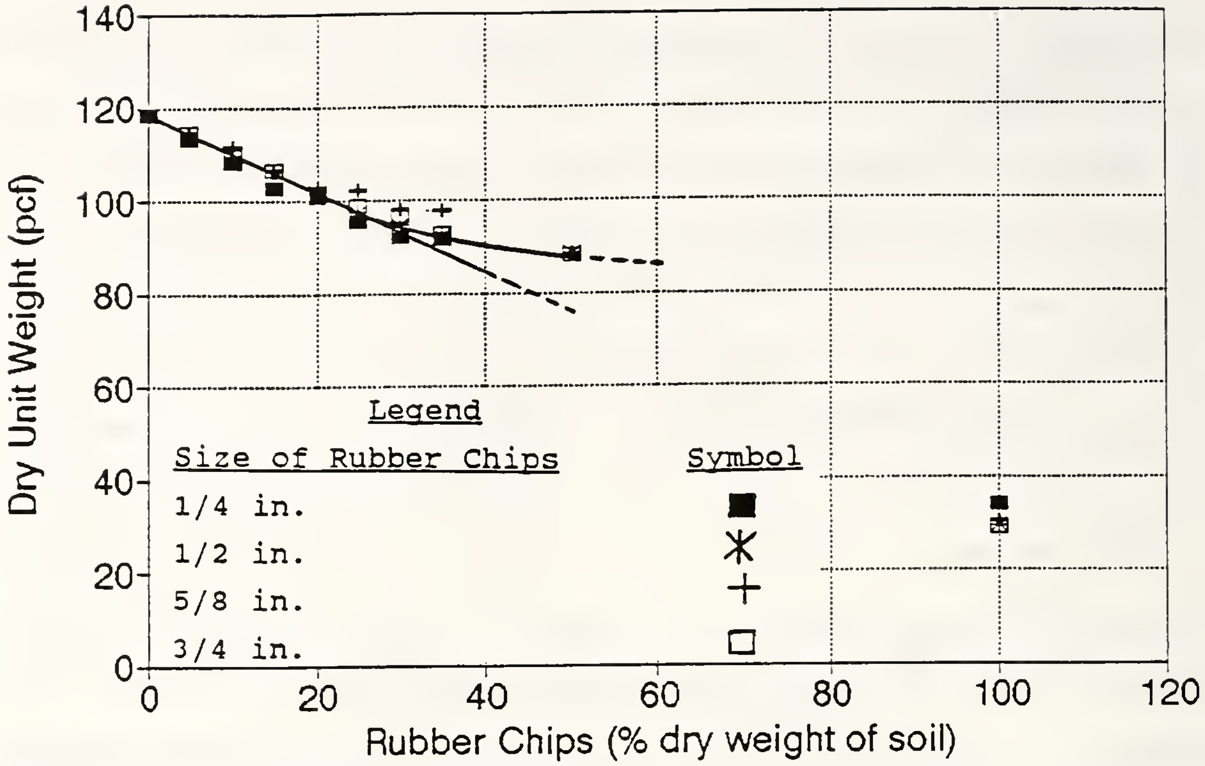

Figure 4.4: Density Versus Percent Chips for Rubber-Sand Using a Vibratory Table.

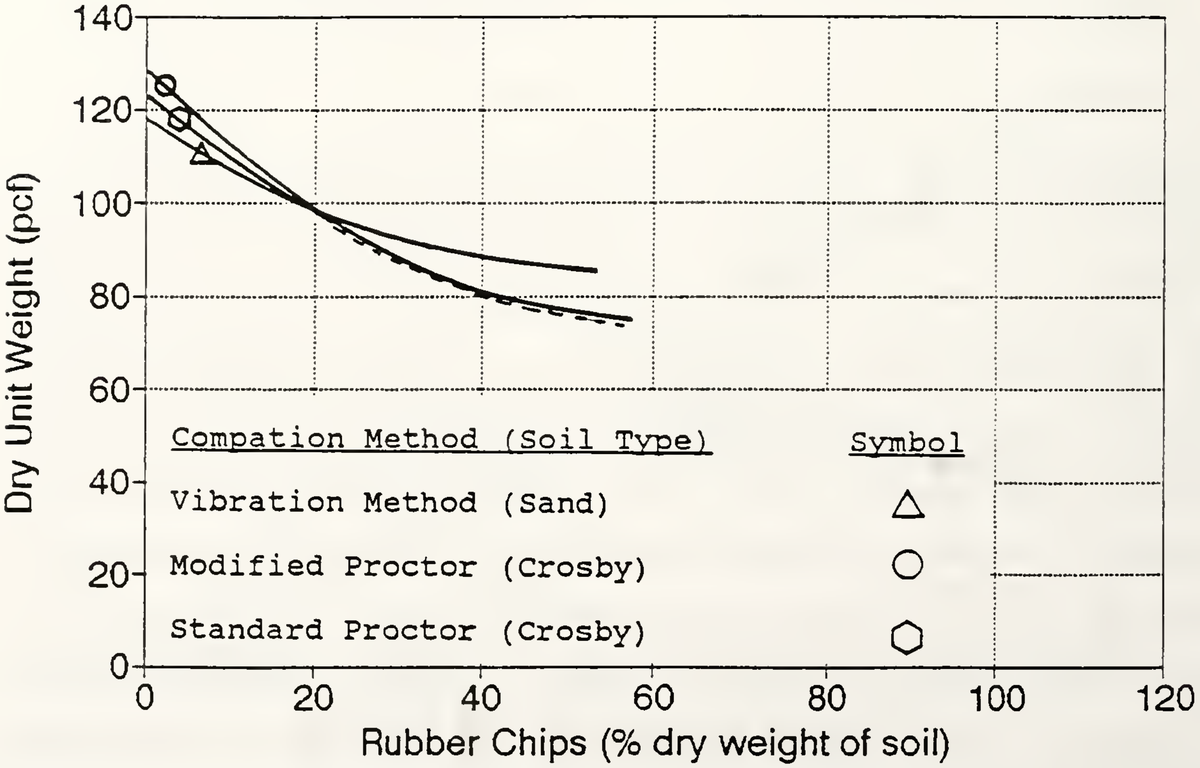

Figure 4.5: Comparison of Compaction Curves from Tests on Rubber Soils (Tests on Tire Chips/Sand and Crosby Till Mix).

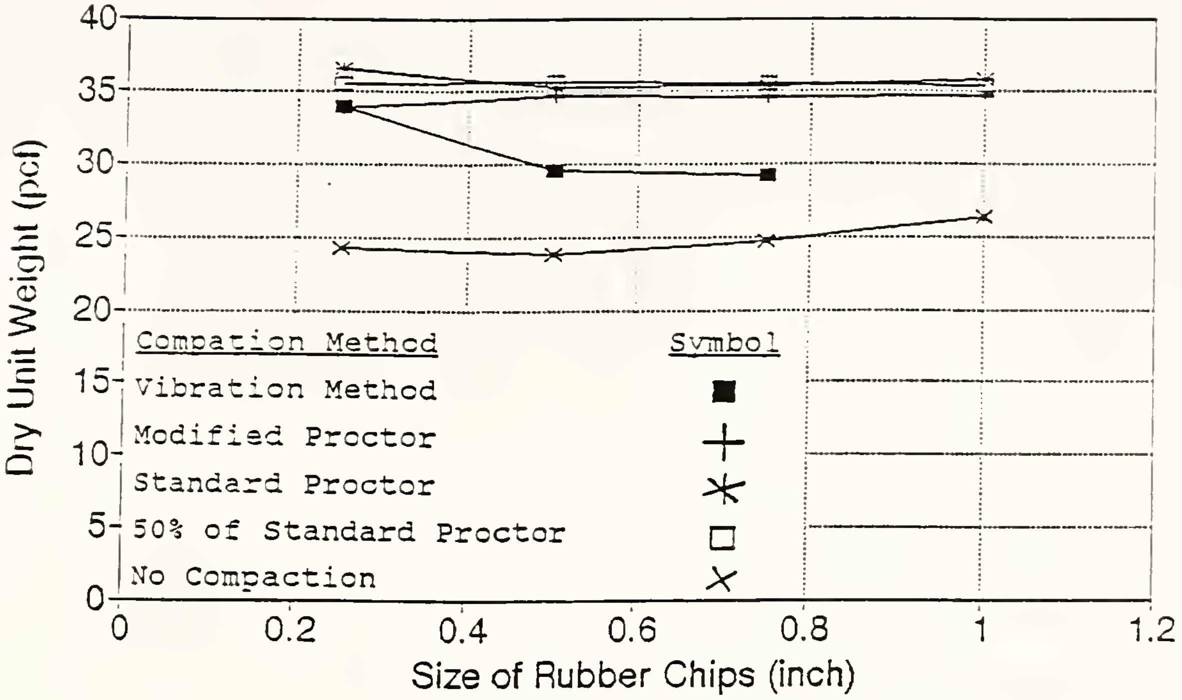

Figure 4.6: Density Versus Size of Rubber Chips.

equivalent of standard Proctor method (see Figure 4.3). It appears that with this amount of rubber chips (i.e., 40% of weight of dry soil), the soil samples accommodate maximum amount of rubber chips without appreciable reduction in the void ratio. Any further reduction in the density of mix can be achieved only at the cost of increased void ratio, which is likely to cause larger compression of the mix under loading conditions. Hence, based on compaction results only, it can be inferred that about 40% of the dry weight of soil is an optimum value for the quantity of chips in a rubber-soil mix, where large settlements are a matter of concern. The size of chips have little effect on the maximum density of rubber-soil. However, a trend of increased density with increasing size of chips is observed. This may be due to increased amount of steel in the large size chips.

Figure 4.4 plots the data from compaction tests on rubber-sand using the vibration method. The trends are almost similar to those observed in the case of compaction test on rubber-Crosby using the Proctor method. The size of chips does not significantly effect the dry density. However, a trend of increasing density was found with increase in the size of chips, with the exception of compaction tests on 5/8 in. size chips which yielded densities greater than 3/4 in. chips. This is presumably due to a more uniform gradation of 5/8 in. size chips (see Figure 4.1), and thus larger voids which when filled with sand increase the density of chip-sand mix.

Figure 4.5 compares the compaction curves from tests on rubber-sand using vibration method and on rubber-Crosby samples using modified and standard Proctor methods. The curves from modified and standard Proctor compaction tests are remarkably similar, except that the maximum density of rubber-soil from modified Proctor is slightly higher than the standard test for up to about 20% of rubber chips (the difference gradually declines from about 5% with no chips to zero with 20% chips), beyond which the curves almost overlap. The results from compaction tests on rubber-sand are almost similar to those observed in the case of tests on rubber-Crosby using Proctor method of compaction, except that they yield lower densities and the density is proportional to percent rubber chips until a value of about 30% chips, as compared to 25% for Proctor compaction. A comparison of all the compaction curves confirms that the value of 40% of dry weight of soil is the quantity of chips in rubber-soil mix which is considered optimum to avoid large settlements. A blend of rubber-soil with chips about 40% of dry weight of soil will yield maximum density about two thirds that of soil alone.

Figure 4.6 compares the compaction results from tests performed on rubber chips using different methods and also varying the compactive efforts on a density versus size of rubber chips plot. It is known that higher compactive effort yields higher dry densities, but this trend was not observed from the experimental results on pure chips. In fact, the opposite of this was found in case of Proctor compaction tests on rubber chips. The density of chips reduced with increase in compactive effort from standard to modified Proctor compaction method. However, the results obtained were almost similar to standard Proctor compaction method when the compactive effort was reduced to 50 percent. The densities of rubber chips obtained from vibratory compaction were lower than those obtained using Proctor compaction method. However, the densities computed without any compaction were the lowest. This indicates that some compaction is necessary, even though the optimum density can be achieved with a modest compactive effort. The size of chips is found to have a negligible effect on the density of chips, except in case of vibration compaction. The density achieved using vibration compaction decreases with increasing chip size, which is expected since smaller size rubber particles rearrange easily under vibration and achieve better packing. However, vibratory compaction is found comparatively not very effective in case of chip sizes larger than 1/2 inch.

4.9 Summary and Conclusions

Two types of soils, representing fine and coarse grained, have been selected and prepared for testing purpose: (1) Ottawa sand - classified as poorly graded sand (SP) according to USCS and A-3(0) as per the AASHTO classification system; and (2) Crosby Till - classified as sandy silty clay (CL-ML) as per USCS and A-4(0) according to AASHTO. Shredded tire samples of sizes ranging from sieve No. 4 to 2 in. plus have been procured from various tire processing agencies. The first phase of this study consisted of determining the compaction behavior of rubber soils. In the subsequent phases of this study, stress-strain and strength behavior of compacted rubber-soils will be determined under static and dynamic loading conditions. A 6-inch diameter triaxial cell and a 12-inch diameter compaction/compression mold have been prepared for this purpose. The MTS system will be used to impose the static and dynamic loading conditions. Necessary modifications in hardware and software have been completed to acquire the data automatically during the testing.

During the compaction phase of this study, the testing program was formulated to develop quantitative information about the compaction characteristics of rubber soils and chips alone. The variables considered included: compaction methods, compactive efforts, tire chip sizes, and the rubber chip/soil ratios. The compaction tests were conducted following methods described in ASTM specifications D 698 (AASHTO: T99-61), D 1557 (AASHTO: T180-61) and D4253. Three different compactive efforts were used, i.e., modified Proctor, standard Proctor, and 50% of standard Proctor. The tire chips of seven different sizes ranging from sieve No. 4 to 2 inches plus are being investigated in this study. The soil/chip ratios were varied from pure soil to pure chips (i.e., quantity of rubber chips was varied from 0 to 100% of dry weight of soil).

The following conclusions are drawn, based on a critical analysis of the results obtained from the compaction testing of rubber soils and rubber chips alone.

- Vibratory methods of compaction are suitable for rubber-sands. Non-vibratory methods (e.g., Proctor type compaction) are more appropriate for compacting mixes of chips and fine grained soils.
- The effect of compactive effort on the resulting density of rubber soils decreases with increasing chip/soil ratios. Only a small effect is observed for the amount of chips greater than 20% of dry weight of soil. Similarly, the density of chips alone are also not much affected by the compactive effort. Only a modest compactive effort is required to achieve the maximum density of chips. This density is about one third that of the conventional soil fills.
- The chip density is not very sensitive to the size of chips. However, a trend of increasing density with increasing chip size is found, except in the case of vibratory compaction. In this case the maximum density decreases with increasing chip sizes.
- A blend of rubber-soil provides a mix with lower void ratio, which is likely to settle less than fill of pure chips and also cause lesser settlement of foundation soil due to reduced weight of fill. About 40% chips by weight of soil is an optimum value for the quantity of chips in

a rubber-soil mix, where large settlements are a matter of concern. This chip/soil ratio will yield compacted dry density of rubber-soil mix which is about two thirds that of soil alone.

SECTION 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Background

Scrap tires by the millions are discarded annually in the United States and other developed countries of the world, the bulk of which is currently landfilled or stockpiled. This consumes valuable landfill space, creates a fire hazard, and provides a breeding ground for mosquitos. Efforts to sharply reduce the environmentally and economically costly practice of landfilling have stimulated the pursuit of non-landfill disposal or reuse of waste tires. Several beneficial uses for tires have been proposed in the past and some have been put into practice in various highway and non-highway applications. Due to continuous and high volume of materials it requires, the highway industry is often looked upon as a potential consumer of waste products.

The 1991 Indiana Legislature passed Senate Bill No. 209 and House Bill 1056 dealing with the potential use of waste materials in road construction. Portions of these bills address the use of waste tires in highway construction. The bills require the Indiana Department of Transportation (INDOT), in cooperation with state universities, to study the feasibility of using waste tires in road construction. The INDOT has been using recycled or waste products, including tires, in those applications which have been proven effective. They are also constantly engaged in research to find an alternative source of material supply to offset the rising costs of quality natural aggregate, waste disposal, and energy (see Ahmed, 1991). This study is motivated by the INDOT's commitment to promote the use of waste products in highway construction and also to satisfy the requirements of Senate Bill No. 209 and House Bill 1056.

5.2 Summary

This study, based on comprehensive laboratory testing and evaluations, will assess the technical, economic, and environmental feasibility of using shredded tires in construction of highway embankments as a lightweight fill or as a soil reinforcement material. The study primarily focuses on determining compaction and stress-strain-strength behavior (under static and dynamic loading conditions) of compacted rubber soil samples. In addition, the study will briefly analyze economic and environmental aspects of this application of waste tires. The findings of this study will allow the INDOT to determine technical implications, economic benefits and environmental consequences of using shredded tires in highway embankments.

The researcher is currently engaged in conducting various tasks required to accomplish the research objectives set forth in

Section One. Two types of soils, representing fine and coarse grained soils, have been selected and prepared for testing purpose: (1) Ottawa sand - classified as poorly graded sand (SP) according to Unified Soil Classification System (USCS) and A-3(0) as per AASHTO; and (2) Crosby Till - classified as sandy silty clay (CL-ML) as per USCS and A-4(0) according to AASHTO. Shredded tire samples have been procured from various tire processing agencies. A 6-inch diameter triaxial cell and 12-inch diameter compaction/ compression mold have been prepared for static and dynamic testing of compacted rubber-soils specimens to determine stress-strain and strength behavior of rubber-soil mix. The MTS system will be used to simulate the static and dynamic field loading conditions. Necessary modifications have been made in the hardware and software to impose the required loading conditions and acquire the data automatically during the testing.

During this phase of the laboratory study, the testing program was formulated to develop quantitative information about the compaction characteristics of rubber soils and chips alone. The variables considered included: compaction methods, compactive efforts, tire chips size, and the rubber chips/soil ratios. The compaction tests were conducted following methods described in ASTM specifications D 698 (AASHTO: T99-61), D 1557 (AASHTO: T180-61) and D4253. Three different compactive efforts were used, i.e., modified Proctor, standard Proctor, and 50% of standard Proctor. The tire chips of seven different sizes ranging from sieve No. 4 to

2 inches plus are being investigated in this study. The soil/chip ratios were varied from pure soil to pure chips (i.e., quantity of rubber chips was varied from 0 to 100% of dry weight of soil).

This report presents literature review and the compaction phase of the laboratory study. The report is structured as follows: Section One gives the background, research objectives, and research approach to accomplish the stated objectives; Section 2 contains an overview of current practice in recycling, reuse, and disposal alternatives and also presents a discussion on the various options available to reduce the tire disposal problem; Section 3 briefly describes the various lightweight materials traditionally used in highway construction, gives characteristics of tires, and summarizes the various field and laboratory studies on the use of shredded tires as lightweight fill; and Section 4 describes the test materials and testing equipment/procedures. It also presents and analyzes the results from compaction of rubber-soils and tire chips alone. The conclusions and recommendations of this study are presented in the subsequent subsections.

5.3 Conclusions

The tentative conclusions, based on an analysis of limited data on rubber-soils from this study and that reported in the literature, are as follow:

- The various options available to reduce the scrap tire disposal problem include: the reduction of waste tire generation; reuse of chemically unaltered material, in whole tires or after processing; the reclaiming of rubber, constituent materials, or chemicals from scrap tires to recycle them in the manufacture of new products; and the recovery of heat value. Of all the options currently available for the disposal of scrap tires, no single option appears to be so outstanding as to singularly significantly minimize the tire disposal problem, economically and also in an environmentally acceptable manner. Many options/processes need to be simultaneously tried and developed to solve the problem.

- Waste tires may be recognized as a valuable raw material. The factors which favor recycling and must be exploited, include: high physical and chemical durability, elastic in nature, intrinsically high tensile strength, lighter in weight, high calorific value, low costs, and positive impact of recycling on environments. Factors which are impediments to recycling and must be considered while exploring/trying various recycling processes, include: inherently complex chemical composition and manufacturing process, which makes them bulky, resilient, practically non-destructible, potentially combustible, and difficult to separate it into ingredients; variability within the same type and also within different categories of tires; and questionable leachates under adverse environmental conditions.

- Of the available options in source reduction (i.e., longer service life, reuse, and retreading), reuse and retreading are economically/commercially viable and environmentally desirable options. Retreading holds greater promise for significant reduction in the waste stream. An increasing trend in retreading truck, bus, heavy machinery, and aviation tires and a decreasing trend in automobile tires is observed. Reduction in scrap tire generation can be encouraged by various measures, including regulatory requirements and economic incentives.
- Burying of whole tires is an environmentally undesirable option and a waste of valuable resources, and should be discouraged either by law or by high disposal fees.
- Processed scrap tires (cut, sliced, or shredded) are easy to handle/transport and occupy smaller landfill space. Scrap tires which cannot be recycled currently may be stored in monofills or installations in such a manner that they have no adverse impacts on environments, until development of technology in the future that may convert scrap tires into a high value product.
- The present technologies to reclaim rubber or separate tires into ingredients do not yield products that can compete, in terms of price or quality, with the similar products in the market. Further research is required to

develop technologies for reclaiming high quality crumb rubber for reuse in manufacturing new tires and other rubber products.

- The potential areas for recycling tires in highways are: use of whole tires and tire sidewalls for soil reinforcement, soil retaining, sound and crash barriers, and erosion control; shredded tires as lightweight fill, in drainage layers to replace coarse aggregate, and mulch for landscaping; and crumb rubber additive (CRA) in asphalt pavements (see Figure 2.1).
- Three highway applications which hold significant potential for future projection are: (1) use of CRA in asphalt pavements; (2) use of shredded tires as lightweight fill; and (3) use of tires and its products for soil reinforcement. The use of asphalt-rubber as crack/joint sealants and SAM's may be further projected since the products have generally performed satisfactorily and are also found cost effective on a life cycle cost basis. Technical, economic, and environmental issues concerning asphalt-rubber and rubber modified asphalt mixtures need to be addressed prior to their extensive use in the pavements (see Subsection 3.6).
- The use of scrap tires and their products in embankments for soil reinforcement and tire chips as a lightweight material have been successful in the field. These

applications consume large quantities of tires with significant engineering benefits. However, technical, economic, and environmental concerns expressed about these uses need to be addressed. (see Bressette, 1984; Caltrans, 1986; 1988; Edil, et al., 1990; 1992; Mn/DOT, 1990; MPCA, 1990, Read, 1991; Read, et al., 1991; Richman and Jackura, 1984; and Williams and Weaver, 1987).

- Non-highway applications which can potentially consume large quantities of waste tires are: breakwaters, artificial reefs, and reclaiming of rubber/other ingredients. A review of available technologies and markets suggest that these applications are not commercially beneficial at this point in time.
- The use of shredded tires in highway construction offers technical, economic, and environmental benefits under certain conditions. The salient benefits of using tire chips are: reduced weight of fill - help increase stability, reduce settlements, and correct or prevent slides on slopes; serve as a good drainage medium, thus prevent development of pore pressures during loading of fills and can also serve as substitute to conventional permeable materials for subdrainage; reduce backfill pressures on retaining structures; provide separation to prevent the underlying weak/problem soils from mixing with subgrade/base material; allow conservation of energy and natural resources; and can consume large quantities

of local waste tires, which has a very positive impact on the environments.

- Potential problems associated with the use of shredded tires in highway embankments include: leachate of metals and hydrocarbons; fire risk; and large compressibility of tire chips. Drinking water Recommended Allowable Limits (RALs) for Minnesota are found to be exceeded under "worst-case" conditions (MPCA, 1990). However, a recent field study reports that shredded automobile tires show no likelihood of having adverse effects on groundwater quality (Bosscher, et al., 1992). However, long term concerns under adverse environmental conditions still persist. Proper soil cover is required on top and side slopes of shredded tire embankment for safety against fire. During construction, normal caution is required to be observed against fire in stockpiled tires or in embankment tires that have not yet been capped with soil.
- Field studies indicate 10 to 15% settlement of tire embankment under 4 to 6 ft. of soil/pavement overburden pressure and average traffic conditions. Potentially large settlements can be reduced by providing a thicker soil cap and using rubber-soil mix instead of chips alone. Detrimental effects of post-construction settlements can be reduced by using tires under flexible pavements only and letting the chips settle under traffic for some time before laying a final surface course.

- The compacted field density of tire chips vary from 20 to 50 pcf depending on the size of the chips, method of compaction, and thickness of layers. A back hoe is found appropriate for spreading the tire chips. A D-8 crawler tractor is considered suitable for effective compaction.
- Vibratory methods of compaction are found suitable for rubber-sands. Non-vibratory methods (e.g., Proctor type compaction) are more appropriate for compacting mixes of chips and fine grained soils.
- The effect of compactive effort on the resulting density of rubber soils decreases with increasing chip/soil ratios. A small effect is observed for the amount of chips greater than 20% of dry weight of soil. Similarly, the density of chips alone is also not much affected by the compactive effort. Only a modest compactive effort is required to achieve the maximum density of chips. This density is typically about one third that of the conventional soil fills.
- The chip density is not very sensitive to the size of chips. However, a trend of increasing density with increasing chip size is found, except in the case of vibratory compaction. In this case the maximum density decreases with increasing chip sizes.
- A blend of rubber-soil provides a mix with lower void ratio, which is likely to settle less than fill of pure chips and also cause lesser settlement of foundation soil

due to reduced weight of fill. About 40% chips by weight of soil is an optimum value for the quantity of chips in a rubber-soil mix, where large settlements are a matter of concern. This chip/soil ratio will yield compacted dry density of rubber-soil mix which is about two thirds that of soil alone.

- Information on the use of shredded tires in highway structures is severely lacking; areas of major concern are: lack of requisite data on stress-strain and strength behavior of chips and chip-soil mix for design and prediction of performance of highway structures; long term impact on environments; and potential economic benefits in the use of tire chips in INDOT facilities.

5.4 Recommendations

It is evident that the waste tire problem in the United States is of great magnitude and has far reaching environmental and economic implications. It is found, based on a critical analysis of the available options for reuse, recycling, and disposal of scrap tires, that no single option can solve this problem. A comprehensive strategy need to be developed and pursued to combat this problem at government, industry, and public levels. Federal, state and local officials need to integrate their efforts to muster support of the people to solve this problem. A five point approach, to be adopted at national and state level, is recommended:

(1) Develop and implement comprehensive laws governing manufacture, discards, disposal, storage, incineration, reuse, and recycling of tires.

(2) Implement measures to reduce the number of scrap tires generated (e.g., source reduction by having lighter and longer wearing tires, reuse, retreading) which may include: regulatory requirements, economic incentives, etc.

(3) Promote use of scrap tires and their products in highway and non-highway applications which hold great promise for consuming large quantities of tires in an environmentally acceptable manner, with significant economic benefits. Three potential areas are identified in each sector for further projection: in highways - CRA in asphalt paving products, shredded tires as lightweight fill, and tires and its products for soil reinforcement; and in non-highway applications - breakwaters, artificial reefs, and reclaiming products through chemical decomposition of tires.

(4) Permit storage of processed tires (i.e., shredded, sliced, or chopped) which cannot be recycled currently, in safe installations/monofills where they have no adverse environmental impacts, for use in the future when technological advances can convert processed tires into high value products.

(5) Allow incineration of tires only in those tire-to-energy facilities which can burn tires or tdf efficiently, while complying with all the emission control regulations.

Prior to extensive use of shredded tires in the INDOT facilities, the following must be accomplished to satisfy technical, environmental, and economic concerns. This will also help the INDOT to develop bid specifications for incorporating shredded tires in highway structures.

(1) Develop stress-strain relationships and strength/ compressibility parameters for rubber-soil mixes, under static and dynamic loading conditions, for a rational design of highway structures incorporating shredded tires and prediction of their performance.

(2) Synthesize information on the ongoing performance monitoring of various shredded tire embankments to develop correlations between field and laboratory data, and also assess long term performance of shredded tire embankments.

(3) Synthesize and analyze the data from the ongoing laboratory and field studies on the environmental impact of using shredded tires in highway structures.

(4) Perform economic analysis of using shredded tires as lightweight fill, considering local conditions.

(5) Determination of in-situ behavior of shredded tire embankment under local environmental conditions is very

important. A prototype test section designed and instrumented is required.

The ongoing research study being conducted by the author will meet the requirements spelled out in items (1) to (4) above. However, the INDOT should plan the construction of a shredded tire test embankment, as suggested in item (5) above. The design parameters and construction specifications of test embankment may be based on final findings and recommendations of this study.

SECTION 6

REFERENCES

Notes:

ASCE = American Society of Civil Engineers

ASTM = American Society for Testing and Materials

DOT = Department of Transportation

ENR = Engineering New Record

FHWA = Federal Highway Administration

NAE = National Academy of Engineers

NAS = National Academy of Sciences

NCHRP = National Cooperative Highway Research Program

NRC = National Research Council

TRR = Transportation Research Record

TRB = Transportation Research Board

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APPENDIX A

SENATE BILL NO. 209

Appendix A

Introduced Version

SENATE BILL No. 209

Introduced by: Gard

__________, read first time and referred to Committee on

DIGEST OF INTRODUCED BILL

Citations Affected: None (noncode).

Synopsis: Recycled materials in road construction. Requires the Indiana department of transportation, in cooperation with the highway extension research project for Indiana and the Purdue University School of Engineering, to study the feasibility of using recycled asphalt, concrete, waste tires, and demolition materials in road construction. Requires the department to report the department's findings to the legislative council, the governor, and the general assembly.

Effective: Upon passage.

A BILL FOR AN ACT concerning recycling.

Be it enacted by the General Assembly of the State of Indiana:

SECTION 1. (a) The Indiana department of transportation established by IC 8-23-2-1, in cooperation with the highway extension and research project for Indiana counties and cities and the Purdue University School of Engineering, shall study the feasibility of using recycled asphalt, concrete, waste tires, and demolition materials in road construction projects undertaken by the department or by the Indiana transportation finance authority established by IC 8-9.5-8-2.

(b) In conducting the study required by this SECTION, the Indiana department of transportation shall:

(1) consider the development of bid specifications to promote the use of; and

(2) analyze the costs, life cycle, and relative availability of;

recycled asphalt, concrete, waste tires, and demolition materials.

(c) The Indiana department of transportation shall prepare a report on the results of the department's study under this SECTION and submit that report to the legislative council, the governor, and the general assembly before July 1, 1992.

(d) This SECTION expires July 1, 1992.

SECTION 2. Because an emergency exists, this act takes effect upon passage.

APPENDIX B

HOUSE BILL NO. 1056

HOUSE ENROLLED ACT No. 1056

AN ACT to amend the Indiana Code concerning the environment.

Be it enacted by the General Assembly of the State of Indiana:

SECTION 1. (a) The Indiana department of transportation established by IC 8-23-2-1, shall, on its own or in cooperation with a state supported college or university, study the feasibility of using recycled asphalt, concrete, coal combustion products, waste tires, and demolition materials in road construction projects undertaken by the department.

(b) In conducting the study required by this SECTION, the Indiana department of transportation shall:

(1) consider the development of bid specifications to promote the use of; and

(2) analyze the costs, life cycle, and relative availability of;

recycled asphalt, concrete, coal combustion products, waste tires, and demolition materials.

(c) The Indiana department of transportation shall prepare a report on the results of the department's study under this SECTION and submit that report to the

legislative council, the governor, and the general assembly before July 1, 1992.

(d) This SECTION expires July 1, 1992.

SECTION 2. IC 13-7-23-2.5 IS ADDED TO THE INDIANA CODE AS A NEW SECTION TO READ AS FOLLOWS: **Sec. 2.5. As used in this chapter, "person" means an individual, a corporation, a partnership, or an unincorporated association.**

SECTION 3. IC 13-7-23-3, AS AMENDED BY HEA 1406 OF THE 1991 REGULAR SESSION OF THE GENERAL ASSEMBLY, IS AMENDED TO READ AS FOLLOWS: Sec. 3. As used in this chapter, "tire" means a continuous solid or pneumatic rubber covering ~~encircling the~~ **that is designed to encircle a** wheel of a motor vehicle (as defined in IC 9-13-2-105(a).

SECTION 4. IC 13-7-23-11, AS ADDED BY P.L.19-1990, SECTION 36, IS AMENDED TO READ AS FOLLOWS: Sec. 11. (a) The waste tire management fund is established for the purpose of assisting the department in the removal and disposal of waste tires from sites where the waste tires have been disposed of improperly.

(b) The expenses of administering the fund shall be paid from money in the fund.

(c) Money in the fund at the end of a state fiscal year does not revert to the state general fund.

(d) Sources of money for the fund are the following:

(1) Fees paid under section 8(a)(4) of this chapter **and IC 13-7-23.2-13(d).**

(2) Fees established by the general assembly for the purposes of this chapter.

(3) Appropriations made by the general assembly.

(4) Gifts and donations intended for deposit in the fund.

SECTION 5. IC 13-7-23.2 IS ADDED TO THE INDIANA CODE AS A NEW CHAPTER TO READ AS FOLLOWS:

Chapter 23.2. Disposition of Waste Tires

Sec. 1. As used in this chapter, "customer" means a person who purchases at least one (1) new tire from a retailer.

Sec. 2. As used in this chapter, "new tire" means a tire that has never been mounted on a wheel of a vehicle.

Sec. 3. As used in this chapter, "person" has the meaning set forth in IC 13-7-23-2.5.

Sec. 4. As used in this chapter, "retailer" means a person engaged in the business of selling new tires at

retail in Indiana.

Sec. 5. As used in this chapter, "tire" has the meaning set forth in IC 13-7-23-3.

Sec. 6. As used in this chapter, "vehicle" has the meaning set forth in IC 9-13-2-196.

Sec. 7. As used in this chapter, "waste tire" has the meaning set forth in IC 13-7-23-4.

Sec. 8. As used in this chapter, "waste tire transporter" means a person who engages in the business of accepting waste tires from retailers and transporting the waste tires to one (1) or more other locations.

Sec. 9. As used in this chapter, "wholesaler" means a person engaged in the business of selling new tires at wholesale in Indiana.

Sec. 10. (a) In each retail establishment in which a retailer sells new tires, the retailer shall post in a conspicuous place a written notice that bears the following statements:

> "Do not put waste tires in the trash."
>
> "Recycle your waste tires."
>
> "State law requires us to accept your waste tires for recycling or proper disposal if you purchase new tires from us."

(b) A notice required by this section must be at least eight and one-half (8.5) inches wide and eleven (11) inches high.

(c) A person who knowingly violates this section commits a Class C infraction.

Sec. 11. A retailer who sells new tires to a customer shall accept waste tires that the customer presents to the retailer at the place where possession of the new tires is transferred to the customer. The number of waste tires that a retailer is required to accept from a customer under this section is equal to the number of new tires that the retailer sells to the customer.

Sec. 12. (a) A retailer shall dispose of waste tires in the retailer's possession by one (1) or more of the following means:

- (1) Delivery to a wholesaler or to an agent of a wholesaler.
- (2) Delivery to a manufacturer of tires.
- (3) Delivery to a facility that:
  - (A) recycles tires; or
  - (B) collects tires for delivery to a recycling facility.

(4) Delivery to a permitted final disposal facility regulated under IC 13-7.

(5) Delivery to a waste tire storage site (as defined in IC 13-7-23-5).

(6) Delivery to a facility operated as a waste tire cutting facility under a permit issued by the commissioner.

(7) Delivery to a registered waste tire transporter or a person who operates a municipal waste collection and transportation vehicle licensed under IC 13-7-31.

(b) A person referred to in subsection (a) is not required to accept waste tires from a retailer.

Sec. 13. (a) This section does not apply to a person who operates a municipal waste collection and transportation vehicle licensed under IC 13-7-31.

(b) A person may not act as a waste tire transporter unless the person is registered with the department as a waste tire transporter. A person who registers with the department as a waste tire transporter shall disclose the following:

(1) The person's name.

(2) The address of the person's principal office.

(3) The addresses of any offices maintained by the person in Indiana.

(c) The rules adopted under section 14 of this chapter must adopt a manifest form and require a waste tire transporter to prepare and carry a manifest based upon that form each time a waste tire transporter transports waste tires. The format and wording of the form must require a waste tire transporter to enter information in each manifest indicating the source and number of waste tires to be transported and the destination to which the waste tires are transported.

(d) Until the rules prescribing a manifest form are adopted under subsection (c), a waste tire transporter may use a manifest form designed by the waste tire transporter. A form designed and used under this subsection must meet the format and wording requirements set forth in subsection (c).

(e) A person who acts as a waste tire transporter in Indiana shall pay an annual registration fee of twenty-five dollars ($25).

(f) Within thirty (30) working days after a waste tire transporter transports a quantity of waste tires, the waste tire transporter shall transmit to the department one (1) copy of the manifest concerning the transportation of the quantity of waste tires.

(g) Each manifest copy received by the department under this section is a public record under IC 5-14-3 and shall be made available to the public for inspection and copying during normal office hours, unless the information in the manifest is determined to be confidential data under IC 13-7-16-3.

Sec. 14. The solid waste management board shall adopt rules under IC 4-22-2 and IC 13-7-7 to implement this chapter.

Sec. 15. This chapter expires January 1, 1994.

SECTION 6. (a) The following definitions apply throughout this SECTION:

(1) "Cutting" means to cut a waste tire into eight (8) or more parts.
(2) "Person" has the meaning set forth in IC 13-7-23-2.5.
(3) "Tire" has the meaning set forth in IC 13-7-23-3.
(4) "Tire piece" means one (1) of the parts into which a waste tire is separated through cutting.
(5) "Waste tire" has the meaning set forth in IC 13-7-23-4.
(6) "Waste tire cutting facility" means a facility at which waste tires are:
  (A) stored above ground before cutting; and
  (B) subjected to cutting, either by equipment permanently located at the site or mobile equipment operating temporarily at the site.

(b) A person may not operate a waste tire cutting facility unless the person holds a permit issued under this SECTION. To obtain a permit for the operation of a waste tire cutting facility, a person must do the following:

(1) Submit to the department of environmental management a description of the facility for which the permit is sought, including a description of:
  (A) the location of the facility;
  (B) the buildings on the site of the facility and equipment to be used on the site;
  (C) the area within the facility that is to be used for the storage of tire pieces; and
  (D) the maximum amount of cubic yards of tire pieces that the person will store at the facility.
(2) Submit a written, signed commitment to store tire pieces at the facility only in compliance with

subsection (g).

(c) A person that operates a waste tire cutting facility under this SECTION shall pay a fee of one hundred dollars ($100):

(1) upon being issued a permit under this SECTION; and

(2) once in each year that the permit is in effect, beginning one (1) year after the issuance of the permit.

The proceeds of this fee shall be deposited in the waste tire management fund established under IC 13-7-23-11.

(d) The commissioner may not issue a permit to a person under this SECTION unless the person has established an escrow account that would be available to the commissioner to pay the cost of removing the waste tires and tire pieces from the site of the person's facility if the person ceased operations at the facility and was unwilling, unable, or unavailable to remove the tires and tire pieces from the site, and removal was necessary to protect the environment. A person that operates a waste tire cutting facility under this SECTION shall deposit in the account four dollars and eighty cents ($4.80) per cubic yard of tire pieces stored at the facility until the amount of money in the account equals the maximum amount of cubic yards the person submitted under subsection (b)(1)(D) multiplied by four dollars and eighty cents ($4.80). When the amount of money in a person's account equals the maximum amount of cubic yards the person submitted under subsection (b)(1)(D) multiplied by four dollars and eighty cents ($4.80), the person may store waste tires at the person's facility without depositing additional money in the person's account if the amount of cubic yards of tire pieces stored at the facility does not exceed the maximum amount of cubic yards the person submitted under subsection (b)(1)(D).

(e) A person may not store more than the maximum amount of cubic yards of tire pieces submitted under subsection (b)(1)(D) at a waste tire cutting facility unless the person:

(1) obtains the commissioner's approval; and

(2) deposits an additional four dollars and eighty cents ($4.80) for each cubic yard of tire pieces stored at the facility that exceeds the maximum amount of cubic yards submitted under subsection (b)(1)(D).

(f) A person may receive a refund of all or part of the money the person has deposited in an escrow account established under subsection (d):

(1) before the person ceases operations at a waste tire cutting facility if:

(A) the person applies to the commissioner in writing;

(B) the amount of cubic yards of tire pieces stored at the facility multiplied by four dollars and eighty cents ($4.80) is less than the amount of money the person has deposited in the escrow account; and

(C) the commissioner approves the refund; and

(2) after the person ceases operations at a waste tire cutting facility if:

(A) the person applies to the commissioner in writing; and

(B) the commissioner determines that the money is not needed to remove waste tires and tire pieces from the site of the person's facility.

Interest that accrues on money deposited in an escrow account may not be refunded.

(g) At a waste tire cutting facility operated under this SECTION, tire pieces may be stored outdoors in banks. However, the storage of tire pieces at a waste tire cutting facility is subject to the following restrictions:

(1) A bank of tire pieces may not be more than:

(A) twenty (20) feet high;

(B) fifty (50) feet wide; or

(C) one hundred fifty (150) feet long.

(2) Two (2) adjacent banks of tire pieces must be separated by a fire lane at least forty (40) feet wide.

(3) A bank of tire pieces must be at least one hundred (100) feet away from the boundary of the property on which the tire cutting facility is located.

(h) The commissioner shall issue a permit under this SECTION for the operation of a waste tire cutting facility to a person who applies for the permit, submits the description and written commitment required by subsection (b), and establishes an escrow account as required by subsection (d). A permit issued under this section is effective for:

(1) five (5) years; or

(2) the period requested in the permit application, if that period is less than five (5) years.

(i) The following shall be incorporated as the conditions applying to a permit issued under this SECTION:

(1) The requirement to pay an annual fee of one hundred dollars ($100), as set forth in subsection (c).

(2) The requirement to deposit a certain amount in the escrow account for each cubic yard of tire pieces stored at a facility, as set forth in subsection (d).

(3) The restrictions upon the storage of tire pieces set forth in subsection (g).

(j) This SECTION expires on the earlier of the following:

(1) July 1, 1992.

(2) The date on which rules adopted by the solid waste management board under IC 13-7-23-15 take effect.

SECTION 7. (a) A permit issued under SECTION 6 of this act is not rendered invalid by the expiration of SECTION 6 of this act. However, before or after the expiration of SECTION 6 of this act, the commissioner of the department of environmental management may modify or revoke a permit issued under SECTION 6 of this act in the manner set forth in IC 13-7-10-5 for the violation of any condition of the permit set forth in SECTION 6(i) of this act.

(b) Notwithstanding the expiration of SECTION 6 of this act, money deposited in an escrow account with respect to a waste tire cutting facility under SECTION 6(d) of this act shall remain in the escrow account until:

(1) the permit expires or is terminated and all waste tires and tire parts are removed from the site of the facility;

(2) the commissioner, under the circumstances referred to in SECTION 6(d) of this act, withdraws the money to pay for the removal of waste tires or tire parts; or

(3) financial responsibility for the potential costs of removing waste tires and tire parts from the facility is established through another means according to the rules adopted by the solid waste management board under IC 13-7-23-15.

(c) This SECTION expires July 1, 1997.

SECTION 8. (a) The solid waste management board shall adopt the rules required by IC 13-7-23.2-14, as added by this act, before July 1, 1992.

(b) This SECTION expires July 1, 1992.

SECTION 9. (a) Before July 1, 1991, the commissioner shall adopt guidelines for the issuance of permits under SECTION 6 of this act. The commissioner shall issue permits under SECTION 6 of this act according to the guidelines adopted under this SECTION until the expiration of SECTION 6 of this act.

(b) This SECTION expires July 1, 1992.

SECTION 10. Because an emergency exists, this act takes effect as follows:

SECTION 1 .... Upon passage
SECTIONS 2 through 5 .... July 1, 1991
SECTIONS 6 through 9 .... Upon passage

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