USE OF ASPHALT MILLINGS IN SUBBASE APPLICATIONS

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FINAL REPORT
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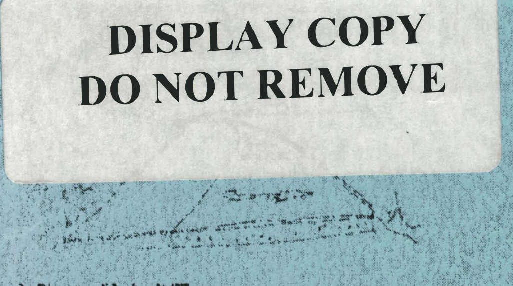

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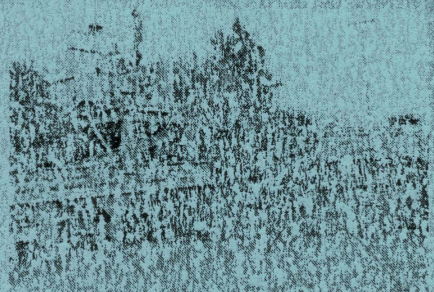

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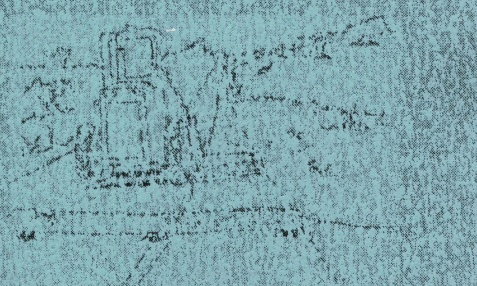

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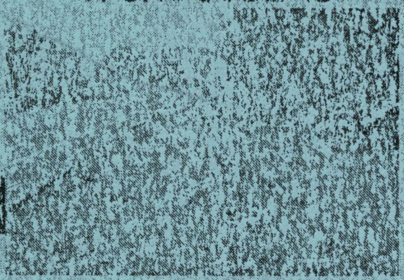

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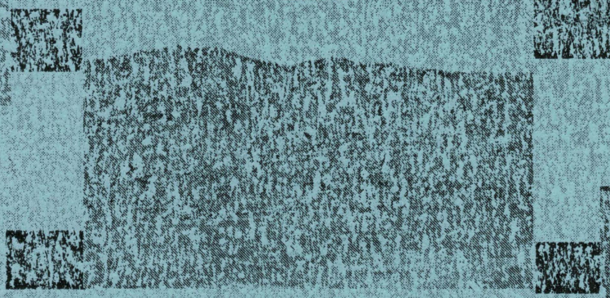

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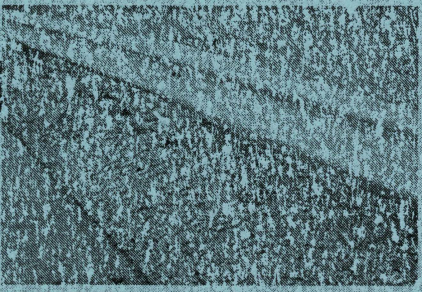

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16. ABSTRACT

Asphalt Concrete (AC) pavements, after a certain period of their service life, exhibit various types of deterioration and damage. To remedy these problems and to increase road safety, they are often overlaid with a new layer of asphalt concrete. Sometimes the old asphalt pavement is milled, and the millings, after being treated with certain chemicals, are used as an overlay. However, the asphalt millings are not entirely utilized in producing recycled asphalt pavements (RAP). Due to environmental as well as economical considerations it is necessary to find alternate uses for these millings. The overall objective of this study is to find how asphalt millings are currently used in Oklahoma, the volume of millings produced in the State, and whether the millings could be used in subbase construction.

A comprehensive literature search was carried out to obtain articles and reports relevant to asphalt millings. The eight Divisions of ODOT were visited and pertinent people from each Division were interviewed. To enhance the information collection process, a questionnaire was prepared in collaboration with the Research, Development and Technology Transfer unit at ODOT for the Divisional people to fill out. The interviews mainly focused on the current milling operations, recycling of millings, methods followed, current use of millings, and potential future use. Photographs of milling operations and milling applications were taken during certain site visits and are included in this report. Also, milling samples were collected during some of these site visits.

The literature survey indicates that processed millings have been used extensively in a variety of applications like shoulder, mailbox turnouts, parking lots, level-up operations, and base/subbase applications in the United States. The divisional interviews revealed that the eight Divisions of ODOT also carry out extensive recycling of asphalt millings. However, due to lack of definite guidelines/specifications for the use of millings in various applications, there have been certain project failures. Aggregate gradation, age of asphalt, milling process, speed of milling operations, age of stockpile and depth of cut primarily affect the quality of millings. Interviews revealed that due to a lack of specific guidelines in subbase application, which are considered critical, the Divisions of ODOT are hesitant in using millings as subbase.

From the study it is concluded that a testing methodology must be introduced for determining the quality of millings in terms of their physical and mechanical properties, relative to their intended use.

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the information presented herein. The contents do not necessarily reflect the official views of the Oklahoma Department of Transportation. This report does not constitute a standard, specification, or regulation.

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ABSTRACT

Asphalt Concrete (AC) pavements, after a certain period of their service life, exhibit various types of deterioration and damage. To remedy these problems and to increase road safety, they are often overlaid with a new layer of asphalt concrete. Sometimes the old asphalt pavement is milled, and the millings, after being treated with certain chemicals, are used as an overlay. However, the asphalt millings are not entirely consumed in producing recycled asphalt pavements (RAP). Due to environmental as well as economical considerations it is necessary to find alternate uses for these millings. It is possible that millings may have some structural benefit as a subbase material; however, dependable data regarding the structural strength, integrity, permeability, or suggested lift thickness is currently lacking. Also, there may be other uses of asphalt millings, such as erosion control, ditch/channel liner, and level-up against the shoulder or under guard rails.

The overall objective of this study is to identify the current and effective uses of asphalt millings in the United States. A more specific objective is to find in what way asphalt millings are currently used in Oklahoma, the volume of millings produced in the State, and whether the millings could be used in subbase construction.

A comprehensive literature search was carried out to obtain articles and reports relevant to asphalt millings. The eight Divisions of ODOT were visited and pertinent people from each Division were interviewed. To enhance the information collection process, a questionnaire was prepared for the Divisional people to fill out. The interviews mainly focused on the present milling operations, recycling of millings and methods

followed, present use of millings, and potential future use. Photographs of milling operations and milling applications were taken during certain site visits and are included in this report. Also, milling samples were collected during some of these site visits.

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From the study it is concluded that a testing methodology must be introduced for determining the quality of millings in terms of their physical and mechanical properties relative to their intended use.

CHAPTER 1 INTRODUCTION

1.1 Background

A majority of roads in the United States consists of asphalt concrete (AC) pavements, which are a mix of asphalt cement (a petroleum-based product), coarse and fine aggregates, and filler. After a certain period of service life, these pavements are found to exhibit various types of deterioration and damage including cracking, permanent deformation (rutting), and disintegration (ravelling). Increased traffic loading, particularly truck traffic, and environmental factors also play an important role towards the loss of strength, stability and cracking of AC pavements. To remedy these problems and to keep the roadways functional and safe, AC pavements are frequently overlaid with a new layer of asphalt concrete. Depending upon the damage to the pavements, it is sometimes necessary to cold mill the existing pavement producing "asphalt millings." The milling depth and composition of asphalt millings, heretofore being referred to as "millings" can vary greatly from project to project and even within the same project. Alternatively, deteriorated asphalt pavements can be completely reconstructed but reconstruction is costly and results in a large amount of waste material that must be disposed of, if not recycled (Crossroads, 1997). A third choice gaining popularity with some state DOTs (Department of Transportation) is "reclaiming." In this approach a pulverizer or milling machine breaks up the existing asphalt surface, leaving the material to be used as a base course for a new pavement. Nationally a huge amount of millings is produced each year. In Oklahoma alone, in 1996, approximately 280,000 tons of millings were generated. Comparatively, in Texas, about 412,500 cubic yards (approximately

600,000 tons) of millings are produced annually, based on a 1992 survey (Estakhri and Button, 1992). Currently there are no specific regulations concerning the disposal of millings. However, with increasing environmental awareness, finding various types of uses for this product is gaining popularity among the state transportation agencies.

Historically, reuse of asphalt pavements in road structures was recognized by 1915 as an important option for pavement rehabilitation (Estakhri and Button, 1992). However, use of asphalt to stabilize recycled materials probably dates back only to the 1930s or 1940s (Estakhri and Button, 1992). Cold milling of asphalt pavements to correct surface irregularities or to remove the old pavement is a common rehabilitation procedure used by various Departments of Transportation (DOTs). Most often the material being milled was originally purchased as a high-quality paving material; therefore, it is logical and economical to find appropriate uses for these millings. The concept of recycled asphalt pavement (RAP) evolved around this premise. In fact, millings and RAP are so much inter-dependent that they are frequently used in the literature interchangeably.

Nationally, guidelines for the use of high quality, uniform RAP for hot recycling, cold recycling, and in-place recycling are fairly developed and are widely used by various DOTs and other highway agencies (Epps et al., 1980). However, in some states this type of recycling utilizes only a portion of the millings generated each year (Estakhri and Button, 1992). Also, some transportation agencies show reluctance to use millings in pavement restoration projects because of quality, transportation costs, and other issues. Moreover, the relative use of millings seems to vary greatly among various DOTs and among various districts/divisions within the same DOT. Laguros and Vavarapis (1990) conducted a literature survey and reported guidelines for asphalt concrete pavements containing hot mix RAP.

An interview with the field Divisions, conducted as a part of this study, indicated that although millings are widely used in Oklahoma for various applications, their utilization as RAP has been rather limited, so far. Details of these field interviews are given in Chapter 4. This study was originally intended to explore the use of millings as a subbase material. Although it is conceivable that millings will have some structural benefit as a subbase, currently no dependable data regarding such properties as structural strength, permeability, and lift thickness are available. Following subsequent discussions with ODOT, the scope of the study was broadened to cover other application of millings, as outlined in this report.

1.2 Objectives

The overall objectives of this study are to identify the current uses of millings in Oklahoma through interviews with the field Divisions and to conduct a literature search to collect information on uses of millings, design guidelines, field performance, etc. A more specific objective is to find how millings are currently used in Oklahoma, what volume of millings is produced in the State, and whether the millings could be used in subbase construction. To document the use of millings in subbase construction and a variety of other applications, the Oklahoma Department of Transportation (ODOT) contracted with the School of Civil Engineering and Environmental Science (CEES), at the University of Oklahoma (OU), under item 2112 (ORA 125-5545) "Use of asphalt millings as subbase". In addition to this effort ODOT prepared a video on the applications and guidelines for the use of millings, as a part of this project.

1.3 Methodology

Information required for this study was primarily acquired through a comprehensive search of literature and interviews of pertinent ODOT personnel from each of the eight field Divisions. Along with these interviews, several field trips were organized by the Research, Development and Technology Transfer office at ODOT to visit some selected sites involving various applications of millings. A few milling samples were collected for laboratory testing in case such a need arises in the future. The discussion presented in this report is primarily based on a careful analysis of information/data from technical reports and publications including journals, conference proceedings and books, and the divisional interviews.

Thus the study tasks included the following three steps:

1) Collect information concerning the use of millings as a subbase and in a variety of other applications.
2) Interview pertinent people in each of the eight Divisions of ODOT to identify the current use of millings, problems faced and potential use of these millings in future.
3) Prepare a report including the findings of the present phase of this project.

1.4 Organization of the Report

This report basically encompasses five chapters. Information regarding the source, database searched, literature collected and a general review of previous studies are presented in Chapter 2. The information/data obtained from the interviews with the personnel from each Division of ODOT are presented and discussed in Chapter 3, while Chapter 4 includes the inferences drawn from this study. The conclusions from this study as well as recommendations for further research are outlined in Chapter 5. A number of test sections have been constructed in Texas and Pennsylvania using RAP and different types of stabilizers, and their performance was monitored. A discussion on the performance of these test sections is presented in Appendix I. Finally, the questionnaire prepared for the interviews of the representatives from each field Division in Oklahoma is presented in Appendix II.

CHAPTER 2 LITERATURE REVIEW

2.1 Source and Database Searched

A comprehensive literature search was conducted in this study to obtain articles and reports relevant to millings. A list of the important Keywords was prepared in collaboration with ODOT and used in various combinations to conduct the computer search. The computer-based search facilities available at ODOT and at OU were utilized for this purpose. Specifically, the following database were searched: TRIS, TRB, Uncover, First Search, Compendex web, and Engineering Information Village. Also, pertinent organizations such as the Asphalt Recycling and Reclaiming Association (ARRA), and the Oklahoma Asphalt Pavement Association (OAPA) were contacted for obtaining information regarding the use of millings in the United States and Europe. Some of the articles collected during this study were obtained from a search of the computer based cataloging system of University of Oklahoma (OU) libraries. Articles not available in the OU library were procured through Uncover (computer-based delivery system) and through interlibrary loans.

2.2 Literature Review

The literature search effort yielded technical reports, journal articles and symposium/conference proceedings articles. Although a large volume of materials is available on asphalt pavements including design, analysis, and performance assessment as well as on testing and mix design, very few systematic, scientific studies have been reported on millings. A good number of articles have reported the success of using millings in a variety of projects, including the cost saving aspects. However, very few articles have discussed the pertinent scientific and engineering issues. Also, in a majority of articles, the main emphasis is given to the use of millings as base, binder, and surface courses. Very few articles are available on the use of millings as a subbase. Several states have developed guidelines concerning the use of millings and some states have instituted policies concerning a mandatory use of processed millings in base, binder, and surface courses. Some states have also reported the field performance of various test sections constructed using millings mixed with appropriate stabilizers/emulsions. A summary of the previous studies is presented in the following sections. However, it should be noted that millings are also used in County roads, but that this experience is not documented in formal reports. Consequently, no scientific engineering information is obtained or disseminated.

2.3 Overview of Previous Studies

This section provides an overview of the projects carried out by several state DOTs and the experience they have gained in the use of millings. Before discussing the findings from these studies, and the different methods currently used for asphalt recycling, a presentation of the relevant terminology is in order.

2.3.1 Terminology in Asphalt Recycling

In terms of materials, the following definitions are pertinent:

- **Millings:** Millings are the material removed by a rotating drum containing multiple teeth from the surface of an asphalt concrete pavement. Sometimes these are referred to as *raw millings* or *asphalt millings*.

- **Processed Millings:** Millings to which additives such as virgin aggregate, anti-strip agent, asphalt cement, emulsions or some other asphaltic material, has been added are called processed or treated millings.
- **Recycled Asphalt Pavement (RAP):** RAP are processed millings from an AC pavement wherein additives such as aggregate and/or asphalt cement or some other asphaltic material has been added and the mix is used as hot mix AC surface course.

In terms of methods, there are five recognized methods of asphalt recycling: cold planing, hot recycling, hot in-place recycling, cold in-place recycling, and full depth reclamation. An overview of these methods is given below.

- **Cold Planing**: In cold planing, the asphalt pavement is removed to a desired depth and width using a self propelled rotary drum cold planing machine. The removed material can then be used as feedstock either at the site or at the mixing plant. This method allows immediate use by regular traffic after planing and the planed surface can be left as a textured surface or re-surfaced at a later time.
- **Hot Recycling**: This in-plant process combines the removed asphalt pavement with new aggregate and an asphalt cement or recycling agent to produce hot mix asphalt which is then hauled to a work site for use. This procedure requires minor modifications to existing hot mix plant equipment.
- **Hot In-Place Recycling**: In this method, the pavement is removed by milling, heated and mixed with recycling agents or additional aggregate and then applied to the road as hot mix in either single or multiple passes. This process re-uses existing asphalt aggregate material and eliminates the cost of hauling waste material between the site and asphalt plant.

- **Cold In-Place Recycling**: In this method, the existing pavement is removed, pulverized, and the road resurfaced with the rejuvenated asphalt material at the same site. This process eliminates some of the hauling costs for materials and has a high recycling production rate (up to 500 tons per hour). Further, one lane of traffic can be maintained throughout the project at all times which may be an attractive option for sites where rerouting of traffic is problematic.
- **Full Depth Reclamation**: When using this method, the full pavement and a predetermined portion of the underlying materials are uniformly crushed, pulverized, or blended with additives, resulting in a stabilized base course when replaced. This is found to be one of the most economical solutions for increasing load-carrying capacity of pavement. Further, this process eliminates potential cracking of new overlays, may be accomplished in-place, allows for maintenance or adjustment of roadway cross-sections, and traffic can usually continue to use the roadway during resurfacing.
- **Cold Process Recycling of Millings**: Figure 2.1 shows a portable stationary plant for processing of raw millings. The plant consists of a crusher to reduce the oversize millings. The millings coming out of the crusher are sieved and then conveyed into a pugmill. An emulsion properly formulated for a specific intended use is added to the pugmill from a tanker truck (Figure 2.2). Computerized methods are then used to control the exact amount of emulsion required (Figure 2.3).

Figure 2.1 Portable Stationary Plant

Figure 2.2 Emulsion Tank

Figure 2.3 Computerized Weighing of Emulsion and Millings

2.3.2 Successful Uses of Millings

With age, asphalt becomes brittle and loses its ability to deform under traffic loading without cracking (Scott, 1993). The recycling process, along with the addition of emulsion softens the asphalt and allows it to regain its ability to deform under traffic loading without cracking. During asphalt recycling, the waste AC is pulverized, sorted, and mixed with recycling agents and additional aggregates, if necessary. The rejuvenated mix is then applied to the road.

From previous studies it is evident that most RAP is used in hot recycled mixtures (Estakhri and Button, 1992). Most well thought out specifications have been developed for hot mixtures. States like Delaware, Georgia, New Hampshire, Rhode Island and South Dakota allow use of higher percentage of millings in mixes produced by drum plants than by batch plants. From Table 2.1 it is evident that millings as high as 70 percent have been used in projects and often less percentage of millings have been permitted in surface applications than in base or binder applications in most states (Estakhri and Button, 1994; and Tia 1993). Table 2.1 also shows that states like Arkansas and Utah using 70 percent millings in projects. Delaware, Indiana, Maryland, Minnesota, Mississippi, Montana, New York, and South Carolina allow higher percentage of millings in base and binder applications than surface applications. Some DOTs permit the use of small quantities of RAP only in base and binder courses and prohibit the use in surface courses except by special permission. The DOTs of Connecticut, Delaware, Georgia, Indiana, Iowa, Kansas, Louisiana, Michigan, Nevada, Ohio, Oregon, Pennsylvania, Washington and Wisconsin allow the routine use of small quantities of RAP in hot mix asphalt concrete (HMAC) (Eaton M., 1990).

A project was undertaken by the Texas Transportation Institute (TTI), under the sponsorship of the Texas Department of Transportation (TxDOT), to study the routine maintenance uses for milled reclaimed asphalt pavement (Estakhri and Button, 1992). Field samples were collected in three locations throughout Texas to characterize the laboratory properties of RAP. Cold mix designs were performed using different emulsified admixtures. The different emulsions that were used during the project were AES-300RP, CRR-60, ARE-68, and MS-1. The effects of these emulsions were evaluated on the properties of the blended RAP mixtures. Fourteen field projects were evaluated to identify and evaluate existing departmental uses of RAP, investigate and

Table 2.1 Successful Uses of Millings as Base, Binder and Surface Courses

STATES	% BATCH			% BINDER			
	BASE	BINDER	SURFACE	BASE	BINDER	SURFACE	TOP SIZE FOR MILLINGS
Alabama	40	40	12	40	40	40	2"
Alaska	NO STANDARD SPECIFICTION						
Arizona	40	40	40	40	40	40	1 1/2"
Arkansas	70	70	70	70	70	70	3"
California	50	50	50	50	50	50	2"
Colorado	30	30	30	30	30	30	1 1/2"
Connecticut	40	40	40	40	40	40	< 2"
Delaware	30	30	10	50	50	10	< 1"
Florida	50	30	50	50	30	50	-
Georgia	25	25	25	40	40	40	2"
Hawaii	30	NO	NO	40	NO	NO	1 1/2"
Illinois	VARIABLE			VARIABLE			
Indiana	50	50	20	30	30	20	2"
Iowa	30	30	30	30	30	30	1 1/2"
Kansas	10	10	10	10	10	10	< 2 1/4"
Kentucky	20	20	20	20	20	20	-
Louisiana	20	20	NO	20	20	NO	2"
Maine	40	40	NO	40	40	NO	1 1/2"
Maryland	50	50	30	50	50	30	-
Massachusetts	20	20	10	40	40	10	1 1/2"
Michigan	50	50	30	50	50	30	< 2"
Minnesota	50	30	30	50	30	30	-
Mississippi	30	30	NO	30	30	NO	2"
Missouri	50	50	50	50	50	50	1 1/2"
Montana	50	50	NO	50	50	NO	2"
Nebraska	NOT COMMONLY USED			30	30	50	2"
New Hampshire	35	35	NO	45	45	NO	-
New Jersey	20	20	10	20	20	10	2 1/2"
New Mexico	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	2"
New York	50	50	NO	70	70	NO	2"
North Carolina	60	60	60	60	60	60	2"
North Dakota	50	50	50	50	50	50	1 1/2"
Ohio	50	50	30	50	50	30	< 2"
Oklahoma	25	25	25	25	25	25	< 2"
Oregon	20	20	20	20	20	20	1"
Pennsylvania	OPEN	OPEN	10	OPEN	OPEN	10	< 2"
Rhode Island	35	35	NO	50	50	NO	1 1/4"
South Carolina	20	15	10	20	15	10	2"
South Dakota	NOT COMMONLY USED			30	50	20	1 1/2"
Tennessee	OPEN	OPEN	0	OPEN	OPEN	0	NONE
Texas	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	2"
Utah	70	70	70	70	70	70	< 1 1/2 "
Vermont	MUST MEET STANDARD SPECIFICATION						NA
Virginia	25	25	25	25	25	25	2"
Washington	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
W- Virginia	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
Wisconsin	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
Wyoming	50	50	10	50	50	50	2"

(Estakhri and Button, 1994; and Tia, 1993) assess the value of new uses for RAP and to collect video footage of these activities for the production of videos to support the implementation of RAP by TxDOT. The second phase of the project consisted of monitoring the performance of the field maintenance projects for a period of two years. It was concluded that *the most common problem associated with treated RAP was addition of excessive emulsion*. RAP (both treated and untreated) blended with hot mixed cold laid asphalt concrete (HMCL) was consistently successful with existing base materials, and, with only few exceptions, it proved to be a promising pavement material and quite cost effective (Estakhri, 1994). For example, the Hveem stability values of the mixes were in the neighborhood of 40 and the cost figures were \$ 30/m^3.

Another demonstration project of a substantial nature was undertaken by Pennsylvania DOT (Penn DOT) in Chester County, Susquehanna County, Luzerne County and Mercer County. All the projects were undertaken using cold mix recycling with the addition of emulsion, and the performance of RAP as base course was monitored. The study indicated that a single application of seal coat was insufficient when RAP is used as a base course.

Apart from the use of millings in base, binder and surface courses, they have also been used successfully in driveways, shoulders, level-up, mailbox turnout, parking lots etc. Addition of emulsions and stabilizers has been found to improve the field performance as a maintenance mixture. According to previous studies, AES-300RP, CRR-60, ARE-68, MS-1 and CM-2 are mentioned as the commonly used emulsions. $CaCl_2$ when mixed with recycled materials coats fine particles and gravels, binding them together (Jantzen, 1993). This binding action stabilizes the recycled base, keeping it dense and compact. Liquid calcium chloride assures stability of reclaimed materials because it controls the rate of drying in both the compaction and curing period-regardless of asphalt content and type (Jantzen, 1993). Using full depth reclamation and liquid calcium chloride, the town of Wellsville, New York spent $19,000 to rehabilitate one mile of a badly worn road. To rehabilitate the same road with four inches of new blacktop would have cost $40,000. Many municipalities have achieved significant cost reductions by recycling their roadways (Jantzen, 1993).

In 1990, Laguros and Vavarapis (1990) conducted a literature survey on the performance of asphalt concrete pavements containing hot mix recycled asphalt. It was reported that hot mix asphalt recycling has been utilized by several agencies and has provided significant savings in new materials and disposal costs. However, special in-depth specifications, i.e., special step-by-step design procedures, to cope with the fluctuations in quality of the old pavement material, are required for the successful implementation of hot mix recycling. Although there are many variables involved in a successful recycling process, various studies appear to indicate that the issue centers around "restoring the aged asphalt cement to a condition that resembles that of a virgin asphalt cement". Temperature, gradation, RAP, new AC, mixing plant, equipment and stockpiling are reported to be the main parameters which directly influence the performance of mixes and pavements in question. The equipment for the removal of the old mix involves ripping and crushing or cold milling; however, care should be taken to avoid the lifting of base materials. The depth of removal can be properly controlled, thereby avoiding the contamination of the RAP with the base material, by cold milling, and hence this method is extensively used. It is necessary to coordinate the crushing and mixing operations so as to avoid congealing which results from stockpiling for an extended time. The report also recommends limiting the height of the stockpile to 3 m (10 feet) and using separate stockpiles for the coarse and fine materials to avoid congealing Also, Laguros and Vavarapis (1990) noted that due to the variation in local conditions a specific project in the Woodward area may not be as good as the one in the Broken Bow area.

In Wisconsin, the contractors have been constantly trying to improve their methods to produce better quality roads at the lowest cost (Crossroads, 1997). The least expensive and the most popular approach, according to this article, is to use a machine like rototiller to break up the full depth of the asphaltic pavement and reshaping the surface of pavement to improve the ride or to correct rutting. The pulverized material is reshaped using a grader and compacted to become the base of a new asphalt surface. Uniform depth can be achieved by pulverizing some of the base beneath the pavement along with the asphalt. Gravel may also be added, if necessary, over the pulverized material to increase the depth of the base. Another technique used in Wisconsin involves breaking the asphaltic pavement, crushing to uniform size, and then uniformly spraying or injecting a specified asphalt emulsion inside the machine. An experimental technique is also practiced, which involves injecting water along with hot asphalt emulsion to better coat the reclaimed asphalt milling materials.

The Pavement Recycling Inc. of Rochester, Michigan uses three processes to reclaim county road bases (Brown, 1996). In all these methods, the asphalt is pulverized using reclaiming stabilizers. In one method, emulsion is added to rejuvenate and stabilize the base; another uses liquid asphalt cement, and a third adds calcium chloride solution to the mix. After pulverization the base is compacted, shaped and stabilized. For the emulsion process, initial pulverization is followed by grading, compaction and the addition of three inches of aggregate. The reclaimer then applies emulsified asphalt or other additives at specified rates and stabilizes the base. In Saginaw County, Michigan, the officials estimated that it would cost $78,839 per mile to rebuild a two-lane road with emulsion for the base including a 3 1/2 inch of hot mix overlay, while the liquid asphalt method would have required $92,385 per mile with the same overlay (Brown, 1996). Comparatively, complete removal and replacement would have cost $350,000 to $500,000 per mile depending on drainage and grading requirements. This and other similar field studies have shown that a project cost can be considerably reduced by reclaiming and diverting the savings for complete reconstructions of roads that require rehabilitation.

The City of Tampa, Florida has reportedly extended the life of its asphalt pavements by hot in place recycling of worn-out pavements (Klemens, 1990). Using a Cutler R-2000 hot recycler, the city recycled asphalt streets in-place for about $1 /sq.yd. An overlay of 1/2 inch thick was added increasing the cost to $2.31 /sq.yd. Using this approach the pavement life can be expected to increase by 10 to 15 years. In this process, two lane roads were cut to a depth of 3/4 to 1 inch and the recycled asphalt was compacted to about 80 percent of the maximum density by the recycler's screed. A 1/2 inch overlay of new hot mix asphalt was laid atop the recycled asphalt.

In the Oregon demonstration project, satisfactory recycled mixtures incorporating 80 to 100 percent RAP were designed in the laboratory to meet all of the Hveem mix design criteria (Dumler and Beecroft, 1977; and Rusnak et. al., 1992). But, in actual construction only 70 percent RAP was incorporated in the hot recycled mix due to serious smoke emission problems encountered by using higher percentages of RAP. Smoke emissions with opacities above 20 percent were encountered. The new recycled pavement was rough as compared to an average new hot mix asphalt pavement. But still the new pavement performed well and was able to carry traffic well in excess of the design loadings even after 10 years of service. Hot surface recycling was found to be an effective rehabilitation method to correct surface defects of pavements that were structurally sound (Tia, 1993). The Ontario Ministry of Transportation reported that the performance of hot-surface-recycled mix surface pavements was comparable with the conventionally rehabilitated pavements, though the hot-surface-recycled mix surface looked older and drier (Marks and Kazmierowski, 1992).

The report "Routine Maintenance Uses of Milled Reclaimed Asphalt Pavement" states that most RAP is used in the form of hot recycled mixtures (Estakhri and Button, 1992). In contrast to this the article, "Overview of Recycling of Asphalt Pavements Using at least 80 percent Recycled Asphalt Pavement" (Tia, 1993) states that the overall performance of cold in-place recycled pavements has been very good on a large percentage of the projects in California, Kansas, Maine, New Mexico and Oregon. Supporting these statistics, it has been reported that 9 out of the 13 recycled projects in California have performed well even after five years of service (Epps, 1990). The poor performance of the remaining projects was attributed to moisture damage, nonuniform distribution of binder or excessive binder contents. The cold in place recycling project in Indiana was reported to be performing better than the conventional pavement (Tia, 1993). Of the 52 cold-recycled pavements evaluated in Oregon, 47 had very good performance

(Tia, 1993), thus showing that cold in-place recycling is an equally good option for recycling the old worn out pavement. This potential technology is expected to have significant environmental impact in addition to cost saving.

Millings from a Maryland interstate reconstruction project were used on the jobsite as a base material for lane additions (Kuennen, 1991). A fourth lane was added north- and southbound on I-95 - Maryland's Kennedy Highway - along 10 miles of the 17 miles distance, providing improved capacity to Baltimore's northern fringe. The unique feature on this project was the use of cold recycled millings for subbase underneath bituminous paving. This is one of the few successful applications of millings as a subbase reported in the literature. The millings were placed five inches deep with an asphalt paver over five inches of stone base and compacted to the same density as the stone. Although the millings annealed in the heat of the afternoon, no other additional treatment was performed. The driving surface was ultimately a fast draining, open graded "popcorn" surface with a polymer added to improve performance. The popcorn mix, as an open graded mix, was considered to function adequately to give a better ride and better traction. Also it helped drain the water off the road and hence problems associated with puddling and freezing of the road surface during inclement weather were avoided. Data regarding the performance of the road after the construction were not available and not reported.

Allied Recycled Aggregates, a material recycling division of Allied Demolition Inc., Denver, Colorado takes asphalt from construction demolition and crushes, screens and stores the material on a 32 acre lot (Marquardt, 1994). It has been found that the recycled product compacts faster, has tremendous strength and met all specifications for road base material. Also it is planned to provide this as a base material to homeowners for use under slabs and driveways. As a result, a practical application is found for used material instead of just dumping of such materials in a landfill and, consequently mining for new materials can be cut to minimum.

Apart from the use of millings in base, binder and surface applications, millings have been used for variety of other applications. Estakhri and Button (1992) report that Arkansas, California, Delaware, Montana, Nebraska, Oklahoma, Texas and Wisconsin have extensively used millings for shoulder reconstruction and maintenance. These states have also utilized millings for mailbox turnouts, driveways and level-up operations. The report by Estakhri and Button (1992) gives details of the various applications to which the millings have been put into use in each of the 25 districts of Texas. Use of millings in mailbox turnouts, driveways, and shoulders is extensively carried out in districts 1, 3, 4, 5, 6, 8, 12, 15, 16, 17, 19, 20, and 23 of Texas. Along with these applications, the districts of Texas have also used millings for backfilling edge of pavement, crossovers, litter barrel turnouts, and park-and-ride lot.

Recycling of millings, either by hot or by cold process have led to substantial cost savings (Tia, 1993). Utilization of about 50 percent RAP in recycled hot mix have led to about 15 to 30 percent cost savings as compared to the conventional paving approach (Page, 1988). About 74 percent RAP was used in hot recycled mixture in demonstration project no. 39 in Oregon, thereby leading to cost savings about $220,472 (Rusnak et. al., 1992). The Ontario Ministry of Transportation reported an average cost-savings of 10 to 20 percent when a 40 mm (1.6 in) hot in-place recycled asphalt layer was compared with a 40 mm (1.6 in) conventional hot mix overlay (Tia, 1993; and Marks and Kazmierowski, 1992). The Indiana Department of Transportation, too, has reported that the cold recycling process is significantly less expensive than the hot mixed material as the cost of a plant mixed base was almost three times that of the cold in-place recycled material (Elkin, 1978). Significant cost savings have also been reported in the demonstration project in Utah for the utilization of 70 percent RAP (Betenson, 1980). Detailed description of certain projects in Texas and Pennsylvania is given in Appendix I.

2.3.3 Causes of Failures

Although millings have been used successfully in a variety of applications in the past, lack of specific standards is believed to be responsible for some major problems of rutting and raveling in a number of projects reported in the literature. Various reasons that may have led to a large number of project failures are briefly discussed below:

- Generally, all the reports indicate that problems have been mainly caused due to material variability, improper blending of millings and virgin materials, and improper drainage. The other factors attributed to poor performance are placing tight seal or dense wearing course, placing the cold recycled mixture on a delaminated layer of old pavement, and failure to provide some type of seal before the onset of freeze/thaw conditions. The most critical factor in terms of material variability results from using different asphalt contents and types in pavement layers under consideration (Drake, 1994). The mother asphalt pavement is likely to contain variable asphalt-aggregate compositions at various sites, as a result of which the milled material is expected to have variable chemical compositions. This causes difficulty in employing specific standards for the use of millings. The quality of millings is also affected by the type of milling process, i.e., cold or hot process and thickness of milling. However, the preferable process (i.e., cold milling or hot milling) is still not delineated because both processes have led to both successes and failures. Improper blending of materials naturally leads to poor quality of recycled materials. Finer millings have less strength and as a result they have failed early due to heavy loading imposed by trucks and other vehicles. Millings hold moisture, and if not kept well drained, they are likely to cause rutting and raveling problems.

- One interesting problem associated with millings is that addition of excessive emulsion leads to decrease in the overall performance of the pavement in terms of strength, and stability. Addition of excessive emulsion can cause bleeding through the road surface, forming puddles that prevent the surface from curing evenly (Jantzen, 1993). Adding too little emulsion will affect the base strength. Although addition of emulsion increases the binding action, it causes a decrease in Hveem stability, resilient modulus, and tensile strength if high levels (large amounts) of emulsion are added. As a result, an optimum critical amount of emulsion is required to be added to the milled materials to increase the binding action and performance. Unfortunately the amount of emulsion to be added to reach that optimum percentage is still not easily determined. Application rates and uniformity need adequate control in the field for the success of a project (Jantzen, 1993). Many types of emulsions are available in the market having varying strength and formulations and which ones to use is a question the designer need to address (Jantzen, 1993). Also, some emulsions may be incompatible with the existing surface materials and finding the correct match for a lengthy stretch of a road can be a formidable task.

CHAPTER 3 ASPHALT MILLINGS IN OKLAHOMA

3.1 Introduction

As mentioned earlier, the primary objectives of this study were to identify the current uses of millings in Oklahoma, the amount of millings produced annually in the State, and to investigate if these millings could be used in subbase construction. In order to obtain first hand information about the use of millings in Oklahoma, it was considered necessary to conduct interviews with each of the eight field Divisions of ODOT. In the early stage of the project a meeting was held with the Research, Development and Technology Transfer (RDTT) office of ODOT and the information collection strategies discussed. Based on the inputs received, a questionnaire draft was prepared having questions about the milling operations, stockpiling, recycling of millings, present use of millings, factors affecting the quality of millings, and the potential uses of millings. The questionnaire draft was circulated among some ODOT personnel to obtain additional feedbacks. The finalized form of the questionnaire used in the field interviews is presented in Appendix II. The Divisional visits were arranged by the RDTT office of ODOT. The interviews mainly focussed on the present milling operations, recycling methods used for millings, and present and potential future use of millings. Each visit included at least one researcher from OU and at least one representative from the RDTT office at ODOT. The number of people participating in the interview process varied from Division to Division, but at least two people from each Division participated. In some visits milling samples were collected and these samples are currently stored at ODOT for agents, anti-strip agents, coating enhancers, rejuvenating agents, polymers, or other items in order to modify the emulsion for a specific intended use.

The amount of emulsion added to the millings in the pugmill is very important. The addition of the emulsion should be controlled to within 0.1%. This is best done by a computer, which is using the weight of the material on the conveyor belt to control the amount of emulsion added as well as using a very accurate flow meter. Most cold processes using emulsions require adding about 1.5 % to 2.0 % to the mix. These slightly different rates are usually due to the state of oxidation of the milled asphalt pavement or the presence of some live asphalt.

3.3.1 Division I (Muskogee)

On September 16, 1997, a site visit was arranged to Muskogee, the headquarters of Division I. At the time of this visit, the main milling operations were going on in Muskogee, Cherokee and Haskell counties. The quantity of millings produced in 1996 are given in Table 3.1 which indicates that a total of 7100 tons of millings were produced in 1996, out of which a major quantity (5000 tons) was from the milling operations on US 69 in Muskogee.

Table 3.1 Millings Produced in 1996 in Division I (Muskogee)

Location	Millings (tons)
Muskogee County	1,000
Cherokee County	100
Haskell County	1,000
On US 69 in Muskogee	5,000
Total	7,100

In 1994-95, similar amounts of millings were produced. The production of millings in 1997-98 is also expected to be at the previous year level. During 1992-93, the volume of millings was about 25 percent of the present production amount. It is estimated that about 52,442 tons of millings were recycled in 1996. Table 3.2 gives the stockpile and millings used in each district within Division I. Table 3.2 shows that millings have been primarily used in Muskogee (17,080 tons) and McIntosh (11,309 tons) districts. However, no major use of millings have been reported for Cherokee, Adair and Checotah districts.

Table 3.2. Stockpile and Millings Used in Division I (Muskogee)

District	Stock pile (tons)	Millings used (tons)	District	Stock pile (tons)	Millings used (tons)
Muskogee	1,000	17,080	McIntosh	1,000	11,309
Cherokee	100	894	Okmulgee	250	5,106
Adair	100	446	Wagoner	200	8,000
Sequoyah	100	2,700	Checotah	200	500
Haskel	100	3,040	Sallisaw	500	3,365

Recycling of Millings

In this Division, the millings have been mainly used in level-up/shoulder-up operations and in the treatment of under guardrails. It was estimated that about 85 - 90 percent millings in this Division are used in shoulder-up operations. This Division has used less than five percent millings for erosion control measures; some of these applications have been successful, while others have had problems. The problems were created due to lack of cohesion, allowing the millings to float away. Figure 3.1 shows the

Figure 3.1 Untreated Millings in Erosion Control near I-40 in Sequoyah County

use of untreated millings in erosion control near I-40 on Sequoyah County. Recent observations have shown that a specific type of grass called 'Bermuda' grass grows well in asphalt millings. Figure 3.2 shows the use of untreated millings in shoulder applications on I-40 in Sequoyah County. In the right corner of Figure 3.2, growth of grass is seen on the shoulders which has enhanced the stability of shoulder. It was noted that prior to using millings as base or a subbase, stability and strength tests need to be carried out. The maximum size of millings recommended by this Division for base/subbase operations is two inches and for shoulder operations it is one and half inches.

Quality of millings

The quality of millings is affected by the gradation of millings and the oil content. The gradation of millings in turn depends on the type of material being milled, depth of milling operations, and age of asphalt. The oil content varies due to original mix design, oxidation, etc. The quality of the millings can be assessed by conducting gradation and asphalt extraction tests. Presently this Division carries out only gradation tests for determining the quality of millings. One of the main problems is that different applications require different specifications for millings. For using millings as a subbase the Division would be interested in knowing whether the gradation criterion would be conducive to or reflect adequate stability. It was noted that the presence of fines in millings usually would cause problems in subbases.

Figure 3.2 Untreated Millings for Shoulders on I-40 in Sequoyah County

Although this Division is optimistic about the use of millings as subbase, it would restrict their use as subbase to a limited scale due to lack of confidence about the properties of these materials. Disposal of millings is not considered a problem by this Division.

3.3.2 Division II (Antlers)

On October 28, 1997 a site visit was arranged to Antlers, the headquarters of Division II which has its milling operations at four sites, namely:

1) Two milling operations in McAlester;

2) Durant (on US 69); and

3) County line of Pittsburg and Atoka County on US 69.

The quantity of millings produced in 1996 is presented in Table 3.3. Approximately 10,000 to 10,500 tons of millings were produced in 1996, with the Atoka and Pittsburg counties contributing a major portion, about 3500 tons. The McAlester/Hartford and McAlester/Stipe Blvd. operations have also contributed substantial amounts of millings.

Table 3.3 Millings Produced in 1996 in Division II (Antlers)

Location	Millings (tons)
Atoka - Pittsburg Counties	3,500
McAlester /Hartford	3,000
McAlester/Stipe Blvd.	2,500
Durant	1,000-1,500
Total	10,000-10,500

Prior to 1993-94 all the millings produced during the milling operations were handed over to contractors. In 1995 there were two milling operations in Atoka County, one having approximately 4000 tons (south of SH 131) and the other 2000-2500 tons (1 1/2 miles north of Atoka). From 1992 to 1994 approximately 11000 to 12000 tons of the millings produced were used in various projects. In 1997, approximately 1500-2000 tons of millings were used till the month of August. In 1997, this Division has used millings as base material in McAlester (by pass on US 69). A 100 mm (4 inches) to 150 mm (6 inches) thick base has been constructed on left hand turns using Type A and Type B dense graded mixes over untreated millings. Figure 3.3 shows the use of millings as a base material on left hand turnbays on US 69 McAlester bypass. According to this Division, proper drying of the millings prior to a chip seal can result in a good quality roadway because of the enhanced bonding between the overlay and the seal coat.

Figure 3.3 Millings Used as Base Material on McAlester, US 69 By Pass

Recycling of millings

In this Division, the millings have been mainly used in level-up/shoulder-up operations and under guardrail. Recently this Division has used millings for base operations and erosion control. Figure 3.4 shows the use of millings in shoulder operations on SH 3, near Farris. The total length of shoulder constructed is about 6 miles. The millings were also used for level-up, mail box turnouts, guard rail treatment (Figure 3.5) and erosion control (Figure 3.6 and 3.7). However, it was noted that unsatisfactory performance resulted with the SH 3 project, possibly due to lack of cohesion in the millings. However, because of previous success, this Division is in favor of using millings in level-up and shoulder operations. Based upon the overall experience, this Division prefers to use millings in the following order of preference:

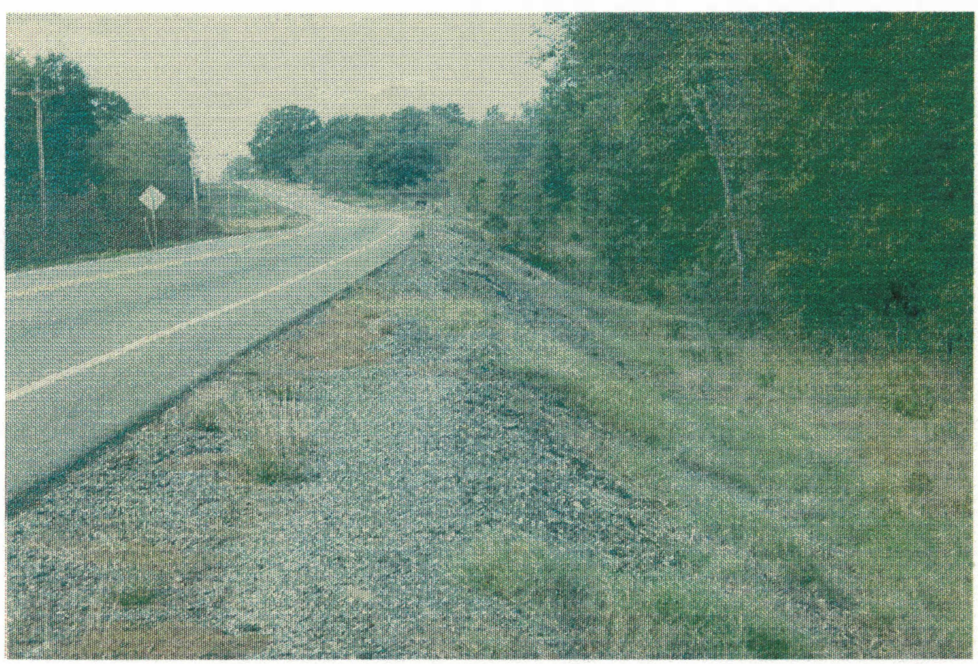

Figure 3.4 Millings Used for Shoulders on SH 3 near Farris

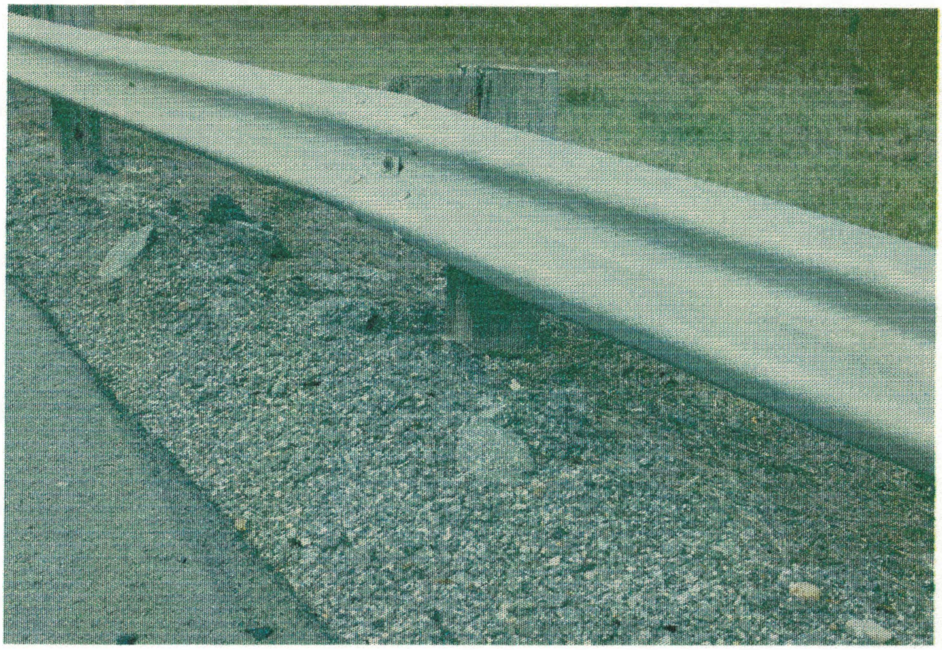

Figure 3.5 Millings Used in Underguard Rail Operations on SH 3 near Farris

Figure 3.6 Millings Used for Erosion Control on SH 3 near Farris

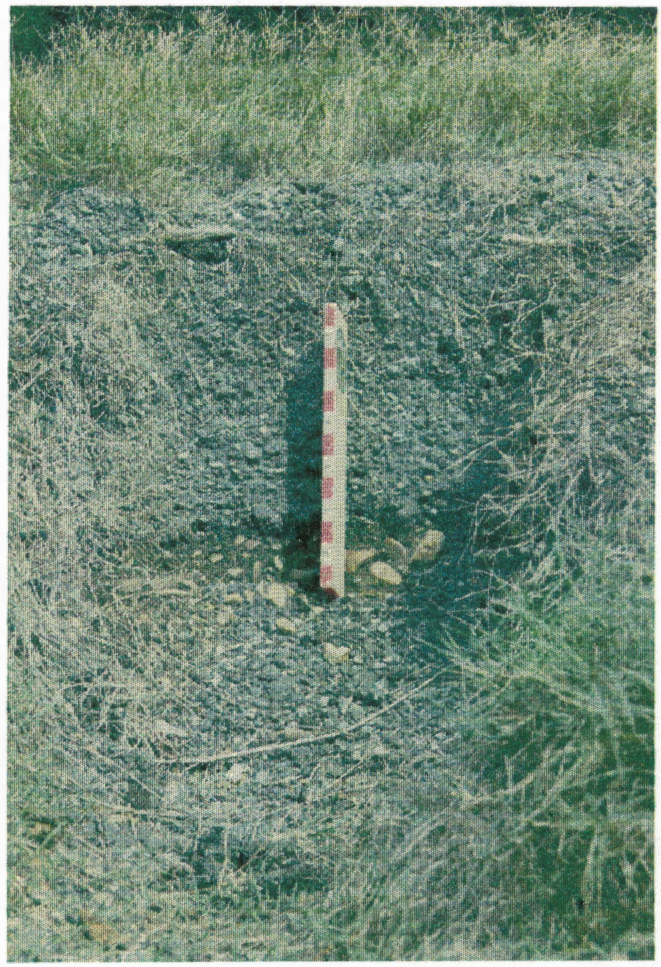

Figure 3.7 Millings Used for Erosion Control on SH 3 near Farris

1) Level-up and Shoulders;
2) Surface Course;
3) Under Guardrail;
4) Base/Subbase; and
5) Erosion Control.

Quality of millings

This Division believes that the quality of millings depends upon the age of asphalt and the presence of a chip seal. For the millings to be of good quality, this Division recommends that the stockpile used for recycling should be preferably less than 1-1/2 years old. Bad odor and presence of dust also indicates poor quality of millings, while darker oil suggests better quality of millings. This Division uses millings of particle size greater than 30mm. Strength, durability, consistency in milling speed, and processing are considered important for maintaining the quality of millings for their use in subbase applications. Presently this Division does not use millings in subbase extensively, but it is very optimistic in using millings for subbase if proper specifications are available. The Division expressed concern about fabric contamination which can be overcome if the millings are put through a crusher and then subjected to a "blower" unit. When stockpiled, millings are being compacted by their own weight or by the dozer working and spreading them. Therefore, if millings are used right away instead of being stockpiled, the product is expected to show better performance.

Disposal of millings is not considered a problem now or in the future.

3.3.3 Division III (Ada)

On September 23, 1997 a site visit was arranged to Ada, the headquarters of Division III. Information regarding the locations of present milling operations is not available. Table 3.4 gives details about the millings produced in each year. Referring to Table 3.4, there is an increase in the quantity of millings from 1992 to 1995 and then a drop of about 22,630 tons in the quantity of millings produced in 1996. Most of the millings produced during these years have been used in shoulder operations and the rest have either been stockpiled for future use or been given to the contractors. In 1997 millings have been used on SH-3 (Coal County) and SH-9 (Seminole County) for shoulder operations.

Table 3.4 Millings Produced Each Year in Division III (Ada)

Year	Specifications	Millings Produced in tons	Use
1992	IR-40-5(171)181	4,582	
1993	MC 25(283)	2,213	Stockpiled
	MC 25(267)	1,384	Stockpiled
	Total	3,597	
1994	MC 25(304)	7,039	Gave away
			3000 tons
	CMC 41(282)	1,196	Stockpiled
	STPY 4413(314)	4,047	Gave away
	STPY 4413(315)	3,577	Gave away
	STPY 4413(316)	1,548	Gave away
	Total	17,407	
1995	MC 32(215)	9,148	Stockpiled
	MC 62(274)	10,114	Stockpiled
	IMY-40-5(329)213	19,388	Gave away
	IMY-40-5(320)173	18,876	Gave away
	IMY-44-1(030)106	13,792	Gave away
	Total	71,318	
1996	MC 25(323)	12,476	Shouldered
	MC 144C(7)	6,860	Shouldered
	MC 154C(001)	545	Stockpiled
	MC 135B(001)	5,642	Shouldered
	MC 162C(001)	9,579	Shouldered
	MC 125B(001)	13,586	Shouldered
	Total	48,688	

Recycling of millings

In this Division, the millings have been mainly used in level-up/shoulder-up operations and in erosion control operations. Crushing and mixing the millings on site, and then using these millings in low volume roads is considered to be a good option. The open graded friction course (OGFC) on SH 19, used in the 1980's, has been milled extensively and it was replaced with hot, 37.5mm (1 1/2inch) thick, Type B dense graded mix, which provided the skid resistance, limited rutting and improved riding quality. According to this Division, the curved sections have to be milled more, about 75mm-125mm (3inches-5inches) than the straight sections, and experience indicates that the cost of a project can be considerably reduced, by using the millings in the same project, since the hauling cost is eliminated. Division III hands over the millings produced to the County for various recycled uses of millings. The Parking lot of the EXPO center (Figure 3.8) in Purcell (Hard Castle road near McDonald on I-35) was constructed from recycled millings; most of the millings in this project were obtained from the milling operations on I-35. The parking lot is functioning well and is considered a major success in asphalt milling recycling. The millings used on SH 3 (Coal County) and SH 9 (Seminole County) for shoulder applications have had moderate success. Based upon previous experience Division III prefers to use millings in the following order (1-high preference, 3-lowest):

1) Level-up;
2) Shoulder reconstruction; and
3) Base/Subbase.

Quality of millings

According to this Division, the quality of millings can vary significantly. The main factors affecting the quality of millings are gradation and AC content of the pavement being milled. However, the specific quality of millings required depends upon the project and the particular use of millings. The quality of millings can be assessed partly by their strength and gradation (the latter to be improved by crushing), as well as the type and amount of asphalt added. Presently the Division considers the use of millings more practical in the reconstruction of shoulders although it has plans to use them as subbase, provided this is viable on a cost basis and the quality is satisfactory. Presently no data regarding the cost for the maintenance operation is available with Division III.

Figure 3.8 Millings Used in the Parking Lot of the EXPO Center in Purcell

3.3.4 Division IV (Perry)

On October 17, 1997 the field questionnaire was distributed among the various counties in Division IV. Detailed information regarding the use of millings was available from this Division. Presently the main milling operations are located in Canadian County (On I-40, US-81, SH-66), Oklahoma County (Reno Avenue) and Ponca city. The amount of millings produced in each of the residencies is given in Table 3.5. In 1997 the El Reno residency produced about 144,361 tons of millings. Table 3.5 indicates that from 1992-97, the El Reno residency has produced the highest amount of millings, except in1994. Kay County produced about 1,000 tons of millings in 1995 while Payne County produced about 100 tons.

Table 3.5 Millings Produced in Division IV (Perry) from 1992-1997

Year	El Reno Residency	Enid Residency	Oklahoma City Res.	Perry Residency	Edmond Residency
	Millings (tons)	Millings (tons)	Millings (tons)	Millings (tons)	Millings (tons)
1997	144,361			9,671	
1996	88,320	15,759	18,000	23,402	25,763
1995	28,128	4,659	21,000		31,552
1994	33,227	39,303	21,000		
1993	78,045	None	29,000		41,934
1992	95,342	None	29,000		

Recycling of millings

The millings produced in this Division have been used for a variety of applications. In the El Reno Residency, about 85-90 percent of the millings were used in RAP and have performed satisfactorily. The rest was used at portable plant sites as driveway/temporary roadway type material. Reno Interstate, Grant County, Perry Residency, Kay County and Payne County have used millings as base/subbase, in erosion control, and level-up/shoulder-up applications. Millings have also been used as ditch/channel liner and mailbox turnouts in various counties of this Division. A good example of use of millings as ditchliner on SH 18 in Payne County can be seen in Figure 3.9 while Figure 3.10 shows the use of millings as shoulders on the same highway. However, in both the applications the millings did not stay in place, thereby leading to failures. There was wide diversity in the preference for the use of millings in different applications. Some Counties prefer to use millings in shoulders, while some others prefer to use them for erosion control and other applications.

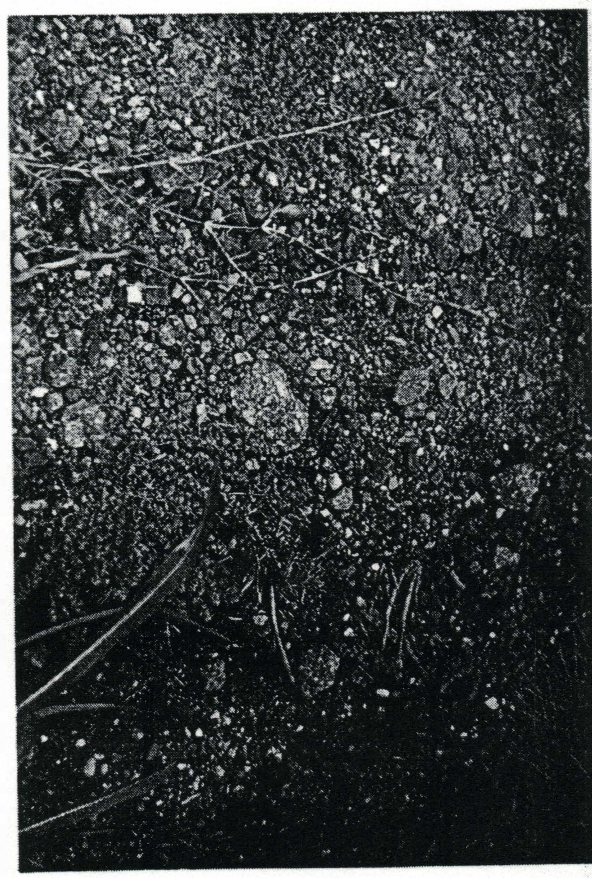

Figure 3.9 Attempted Use of Millings as Ditchliner on SH 18 in Payne County

Figure 3.10 Millings Used as Shoulders on SH 18 in Payne County

Quality of millings

Division IV is believes that the quality of millings is mainly affected by presence of impurities, oil content, gradation, and quality of asphalt used in the original hot mix. The age of the pavement and stripping also seems to affect the quality. At the same time the Edmond and Oklahoma City Residencies indicated that the quality of millings does not vary significantly, and that it could be assessed by conducting laboratory tests to determine the gradation and oil content. The majority of the counties indicated that it would be worthwhile to know the strength, stability and permeability characteristics of millings for possible use in subbase and that specifications must be available to guide such uses. However, due to some past failures, the Reno Interstate personnel are not ready to use millings as subbase. Disposal of millings is not considered a problem because generally they are given to the contractor who is responsible for disposal.

3.3.5 Division V (Clinton)

On October 7, 1997 a site visit was arranged to Clinton, the headquarters of Division V which has its main millings operations in Jackson County, Elk city, and on I-40 (mile post 104 to 115). Jackson County produced 18,000 tons of millings on US 62 east of Altus near Hedrick. A 200-250 mm (8-10 inches) full depth milling was carried out on a 38 ft wide, two miles long road. The Elk city job also produced an excess of millings and are still in stock-pile after five years. The milling operations on I-40 (mile post 109 to 115) produced approximately 6,000 tons of millings that were given to Division VI. In Blaine County there is a stockpile near Watonga on US 270 and SH 3. Volume of millings produced mainly depended on the I-40 repair, but no good data regarding the total quantity of millings produced was readily available from the Division.

Recycling of millings

In this Division also, the millings have been used mainly for shoulder operations and level-up operations. Millings produced in Jackson County have been cold process recycled (1% of HF-300 oil added) and used for shoulder operations. Two years ago processed millings from I-40 were used to construct a 75mm (3inches) thick surface course on SH 183 A near Bessie (Figures 3.11 and 3.12). The mixture used had the following composition: asphalt + HFE-300 + additives (polymer, rejuvenating agent, liquid anti-strip agent, and coating agent). The surface course, even after two years in service appeared in excellent condition and exhibited a good riding quality.

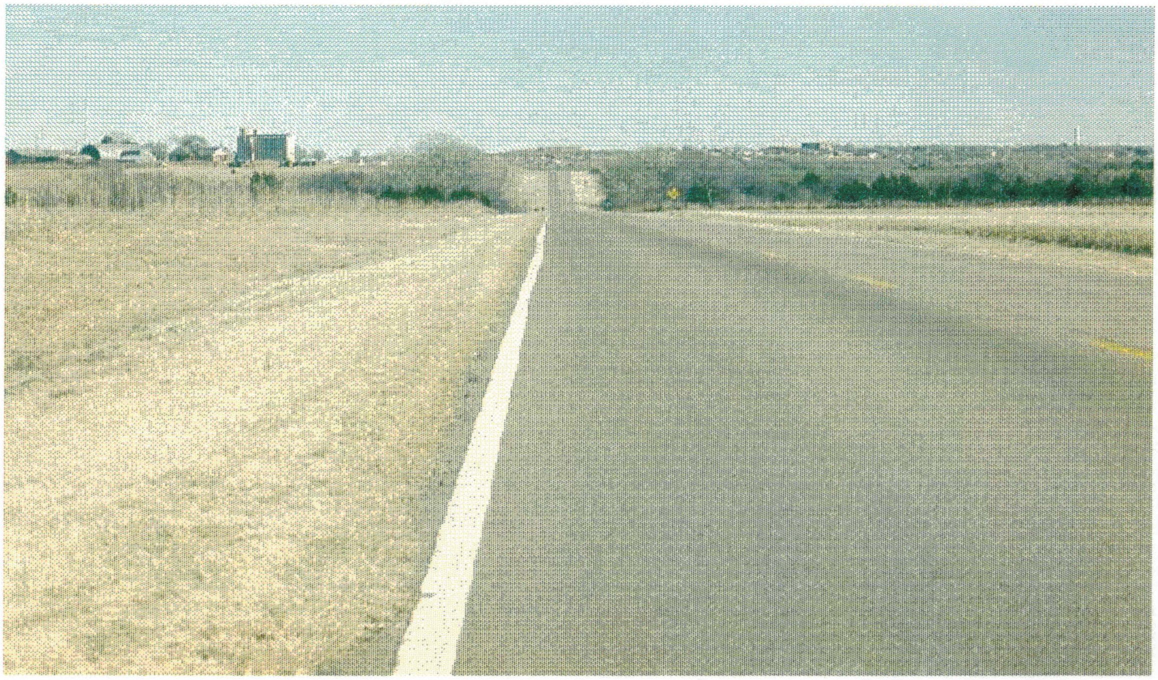

Figure 3.11 SH 183A, 0.77 Mile near Bessie, Looking from US 183 West

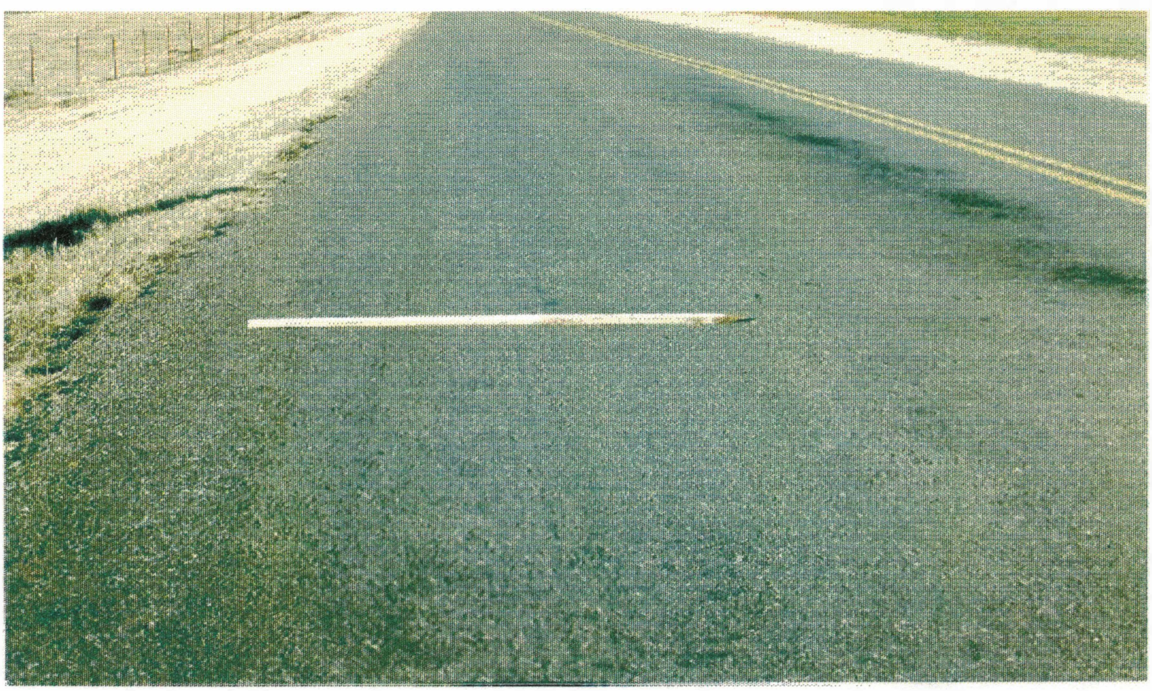

Figure 3.12 75mm Thick Surface Course on SH 183 A near Bessie

In September 1997, millings from I-40 in Custer County (mile post 69 to 76) were used to construct a 610mm (two feet) wide, 125-150mm (five-six inches) thick shoulder east of US 183 on SH 47 in Custer County. The raw millings were crushed and screened. Initially the compaction was done using a pneumatic roller, but small holes were developed in the shoulder as the material stuck to the pneumatic roller. Hence, the rest of the compaction proceeded using a steel wheel roller. The shoulders were then fog sealed after the moisture content was reduced to two percent. The shoulder was performing well and showed no signs of rutting or ravelling. This project used approximately 12,000 tons of millings and the remainder could be used on the shoulder of the Interstate at the contractor's option. Beside these two projects approximately 8,000 tons of millings from I-40 and 6,000 tons derived from various places are stockpiled. Millings from I-40 have been stockpiled at two places: 1) one mile north of Arapaho on US 183 (processed millings), and 2) half mile south on the junction of SH 33 (west) and US 183 (raw millings). On the other hand, millings have also been used as a ditch liner on US 270/281, north of Oakwood in Dewey County, at a campsite in Red Rock Canyon to construct pads for trailers and for fixing pavement edge drop offs, and for the department of public safety and inspector's pads at random locations. Presently the millings in this Division are used in the following order of preference:

1) Shoulder operations;
2) Level-up;
3) Drive ways / drop off / pull out for trucks;
4) Erosion control; and

5) Ditch / Channel liner or Under guard rail.

This Division intends to continue the use of millings in the same way as it is using them now.

Quality of millings

This Division reported that the quality of millings obtained from the top 50-100mm (two-four inches) was generally good, but as the depth of milling operation increased, its quality become a problem. Hot mix processing generally results in good quality of processed millings, and hence Division V adopts only hot mix processing of millings. Workability of the mix is considered to be an indicator of quality of millings. Density, gradation, compressive strength are some of the important characteristics to be considered in assessing the quality of millings.

Presently this Division is hesitant in using millings on driving lanes, even as subbase, because of their experience with bad performance of the SH 34 job. The SH 34 job experienced stripping mainly because the emulsion did not set prior to sealing. But this opinion might change if milling properties are available. All millings are put into use in this Division, therefore, disposal is not considered a problem.

3.1.6 Division VI (Buffalo)

On September 30, 1997, a site visit was arranged to Buffalo, the headquarters of Division VI. Milling operations and stockpiles at each location in this Division is listed in Table 3.6. About 44,000 tons of millings were generated, most of them from the operations in Seiling. From 1992 to 1996 only a limited amount of millings were produced ranging between 1,000 to 11,000 tons. However, in 1997 about 57,000 tons of millings were produced, all of which were generated during the milling operations on I-40. Figure 3.13 shows the stockpile of millings which were generated from the I-40 project. Presently the millings are stored for potential future use. It should be noted that the low volumes are primarily due to the absence of Interstate roads in this Division

Table 3.6 Millings Produced in Division VI (Buffalo)

Location	Millings (tons)
Seiling	27,000
SH 50 in Woodward County	4,000
US 183 and 412	2,000
US 287 North in Cimmaron County	11,000

Recycling of millings

In this Division, the millings have been mainly used for base/subbase operations, erosion control and ditch/channel liner. However, this Division does not have any good experience with erosion control and ditch/channel liner as the millings do not stay in place. In 1997, a 7.3m (24 feet) wide, 250mm (10 inches) deep and 10 miles long stretch of US 64 was recycled inplace with the addition of six percent fly ash and two percent lime and used as a base (Figure 3.14). In this Division, processed millings were used from Chester to Fairview on US 60 to construct a 26 miles long, 0.6 m (two feet) wide and 125-150mm (five-six inches) thick shoulder (Figure 3.15). This used 3,000 of the 5000 tons of millings produced. Although the shoulder showed good riding quality, it had

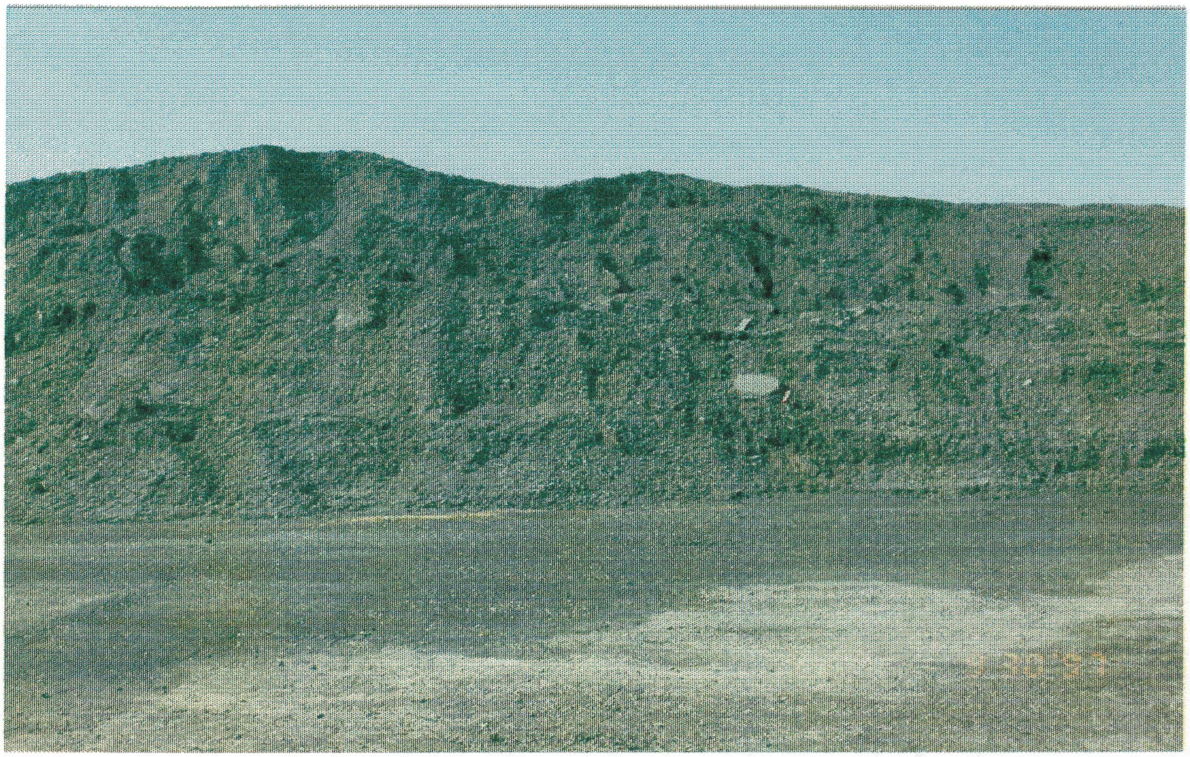

Figure 3.13 Stockpile of Millings From the I-40 Project

Figure 3.14 Millings Used as Base

Figure 3.15 Millings Used as Shoulders from Chester to Fairview on US 60

a slight amount of drop off compared with the rest of the pavement. This may be due to rolling and lack of confinement during rolling compaction. Figure 3.16 shows the pneumatic compaction of processed millings on US 60 near Chester/Fairview. On the basis of its past experiences, Division VI prefers to use millings for widening, pavement layer and base/subbase construction because of good performance achieved so far.

Quality of millings

The quality of millings primarily depends upon their source, the composition of original materials, their age and to a large extent on the type of milling operations. Millings produced from the dense graded mixes of the Interstate roads were of good quality. Density of recycled mix, gradation, oil content, unconfined compression test can be useful to assess the quality of millings. Laboratory durability tests can be conducted to

Figure 3.16 Pneumatic Compaction of Processed Millings on US 60

ascertain the quality of certain aggregates. This Division is definitely interested in using millings as subbase, if the desired characteristics and specifications are available.

3.3.7 Division VII (Duncan)

On October 2, 1997, a site visit was arranged to Duncan, the headquarters of Division VII. This Division presently has three milling operations located at Hinton, Cotton County and Murray County, respectively. The milling operations in Hinton were carried out on US 281 and I-40 on a four miles long and 26 feet wide road. In Cotton County the milling operations were carried out on I-44 about five miles from the Texas border and the depth of milling was 19mm (3/4 inch). In Murray County the milling operations were carried out on I-35 from mile post 52 to 62. The stock piling was done at north edge of Turner Falls near I-35 and I-77 indicating that majority of the millings have come from the Interstate pavements. No significant amount of millings was generated from 1992 - 1994.

Recycling of millings

In this Division millings have been used for pavement layer, under guardrail, erosion control, level-up/shoulder up operations and ditch/channel liner. In March 1997, the millings were also used in slope/slide repair. Figure 3.17 shows the ruts from truck tires at the edge of the pavement in Grady County on SH 9, US 277, and US 62, about two miles NE of Tabler. A 75mm (three inches) drop off is seen in Figure 3.18. This is one of the applications where recycled millings would be a good choice for repair. Table 3.7 gives statistics relevant to the quantities of milled material, their location and use. In 1996, approximately 21,000 tons of millings were produced on SH-53 in Carter County. The millings were used by the contractor in pavement layers on the same as well as other city projects. This Division prefers to use millings in shoulder applications, level-up and erosion control while use of RAP in surface courses is not allowed.

Quality of millings

The quality of millings may vary due to age of millings, contamination, extent of patching, presence of fabric and the general quality of the pavement. While it is basically difficult to get a representative sample for assessing the quality of millings, some measure of the quality can be assessed by determining the gradation, asphalt content, type of impurities and aggregate quality. It appears that two most dominant factors are aggregate size and the strength of millings. Presently this Division has little experience in

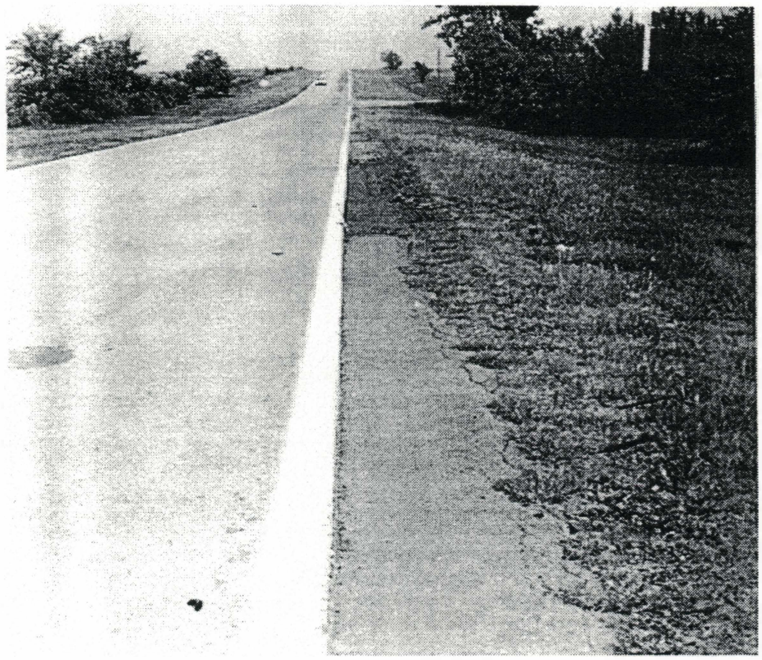

Figure 3.17 Ruts Developed at the Edge of the Pavement on SH 9 in Grady County

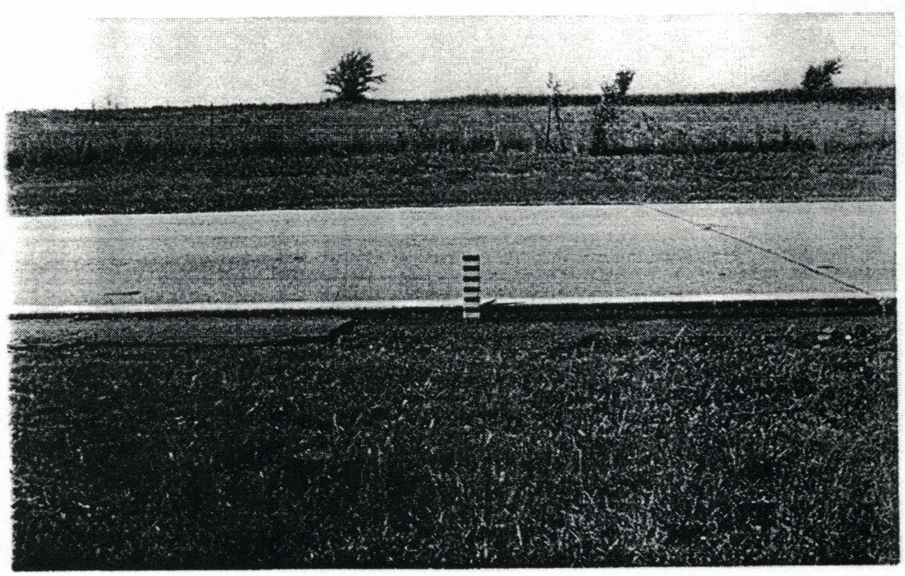

Figure 3.18 75 mm (three inches) Drop Off at the Pavement Edge on SH 9 in Grady County

Table 3.7 Uses of Millings From 1993-96 in Division VII

Project	Appox. Tons Milled	Milled Materials	County	Location	Year
MASTP-514 (106)	1600	Contractors hauled off project. Use unknown	Garvin County	SH-7, Begins approximately 4.5 miles West of I-35,extend east 4.0 miles	1993
IM-35-2 (160)	8000	Stockpiled on Right-of-way at I-35/US 77 overpass for maintenance use.	Murray and Garvin Counties	I-35 , Begins approximately mile 52 extends north to mile 62	1994
NHY-215(57)	4000 plus	Gave to County and percentage used in Asphalt Concrete Type AH	Comanche County	US-62, West end from 1 mile East of Indiahoma, OK to Kiowa County line	1994
NH-215(54)	4000 plus	Gave to County and percentage used in Asphalt Concrete Type AH	Kiowa County	US-62, From Comanche County Line West to approx. 2 miles East of Snyder, OK	1995
OHWD-1005 (102)	21000	Contractors used material in pavement layers	Carter County	SH-53, Begins at I-35 extends east approx. 7 miles	1996

using millings as base/subbase, and its future use in base/subbase applications for such purposes mainly depend upon the volume of material available.

Although, disposal is not a problem, in one unique case, in the Duncan city project, where the existing pavement was completely removed which generated a significant amount of millings with the ensuing problem of disposal.

3.3.8 Division VIII (Tulsa)

On September 16, 1997, a site visit was arranged to Tulsa, the headquarters of Division VIII. In this Division, the stockpiles are located at the following places:

1. Miami DistrictYard;
2. US 59 South;
3. Interstate 44;
4. Gilcrease Expressway;
5. Collinsville at Caney river; and
6. SH 18, Pawnee County.

A large volume of millings was produced in 1992 on US 59. The quantity of millings produced during the milling operations from 1992-1996 is listed in Table 3.8 This indicates that 1992 was the maximum production year.

Recycling of millings

Data regarding the amount of millings recycled is available and is listed in Table 3.9. It is evident that the maximum amount of recycling was carried out in 1993 indicating that the millings from US 59 were used in that year (1993). In all the five years, the millings have been mainly used in shoulders. Figure 3.19 shows the trenching operation for the preparation of shoulders in Pawnee County on SH 18. In this operation too, processed millings were used. Apart from shoulders, this Division also has used millings in level up and base/subbase applications. It has used millings as base/subbase in some cases. Division VIII prefers to use millings as RAP, as base/subbase, level-up and under guardrail.

Table 3.8 Millings Generated in Division VIII from 1992-96

Year	Millings (tons)
1992	5,000
1993	500
1994	2,000
1995	1,000
1996	1,000

Table 3.9 Millings Recycled in Division VIII from 1992-96

Year	Millings (tons)
1992	1,000
1993	4,000
1994	2,000
1995	1,000
1996	1,000

Quality of Millings

The quality of millings is significantly affected by the speed of the milling operation, the depth of cutting and the type of existing asphalt pavement. Generally in this Division, millings have been uniform but occasionally bad quality is encountered especially when fast milling speeds result in larger chunks, thereby lowering the quality. Knowledge of gradation, stability, permeability, and structural strength would help to assess the quality of millings which at present is not or cannot be effected. Presently this Division sees no disposal problems of millings and it is willing to use them as base/subbase, if the desired characteristics and specifications are available. It was indicated that the contractors remained unconvinced as to the use of processed millings as surface courses.

Figure 3.19 Trenching Operations for Shoulders on SH 18 in Pawnee County

CHAPTER 4 INFERENCE FROM DIVISION VISITS

The production of millings in Oklahoma for 1996 is given in Table 4.1 and the data provided by the eight Divisions are presented in a summarized form in Table 4.2. The divisional interviews suggest that each of the eight Divisions of ODOT uses treated (i.e. processed) as well as untreated millings in a variety of applications. In the past, crusher-run gravels have been used for rutfilling, mailbox turnouts, erosion control, etc. However, millings were found to be cheaper and more effective than crusher-run gravels. A majority of the Divisions has been primarily using processed millings for shoulder applications, level-up operations, erosion control and under guardrail. Some of the Divisions have made an attempt to use raw millings in shoulders, mailbox turnouts, erosion control and ditch liners. However, use of raw millings without some type of treatment have caused project failures in the past. One good example of such failure is use of millings in shoulders and erosion control on SH 3 near Farris in Division II (Antlers). This failure was attributed to the lack of binding material. At the same time there are quite a number of project successes when processed millings have been used for shoulders, overlay, ditch liners and a variety of other applications

Divisions I, II, IV, VI and VIII have used processed millings in base/subbase applications. However due to lack of specific standards, the Divisions have been facing certain problems in use of millings in various applications. Certain project failures have taken place, but at the same time due to success in other projects the Divisions have an optimistic approach in using processed millings for shoulders, level-up, underguard rail,

Table 4.1. Millings Produced in Each Division in 1996

Division	Location	Millings (tons)
1	Muskogee County	1,000
	Cherokee County	100
	Haskel County	1,000
	On US 69 in Muskogee	5,000
2	Atoka - Pittsburg Counties	3,500
	McAlester/Hartford	3,000
	McAlester/Stipe Blvd	2,500
	Durant	1,000-1,500
3		48,688
4	El Reno Residency	88,320
	Enid Residency	15,759
	Oklahoma City Residency	18,000
	Perry Residency	23,402
	Edmond Residency	
5	Jackson County	18,000
	Elk city	
	I-40 (mile post 109-115)	
	Blaine County	
6	Seiling	27,000
	SH 50 Woodward County	4,000
	US 183 and 412	2,000
	US 287 N. Cimmaron County	11,000
7	Hinton	
	Cotton County	
	Murray County	
8		1,000

Table 4.2 Summary of Use of Millings in the Eight Divisions of Oklahoma

	Division I (Muskogee)	Division II (Antlers)	Division III (Ada)	Division IV (Perry)	Division V (Clinton)	Division VI (Buffalo)	DivisionVII (Duncan)	Division VIII (Tulsa)
Millings produced (tons)								
1997	25,000			154,032		57,000		
1996	7100	10,500	48,688	172,344		none		1000
1995	192,332	6500	71,318	86,338		5,000		1000
1994	4128		17,407	93,530		1500-2000	no	2000
1993	0		3,597	148,978		11,000	significant	500
1992	0		4,582	124,342		none	amount	5000
Millings recycled (tons)								
1997	0	2000				30,000		
1996	52,442		46,000					1000
1995	30-40 %		42,000					1000
1994	of 1996	about 11,000	17,407					2000
1993	about 10 %	to	3597					4000
1992	of 1996	12,000	4582					1000
How milling materials are used								
Erosion control	about 5%	yes	yes	yes	yes	yes	yes	no
Base / Subbase	about 5%	yes	no	yes	no	yes	no	yes
Under Guard rail	yes	yes	no	yes	yes	no	yes	yes
Pavement layer	no	no	no	no	yes	no	yes	no
Level-up / Shoulder-up	yes (85-90%)	yes	yes	yes	yes	no	yes	yes
Ditch / channel liner	no	no	no	yes	yes	yes	yes	no
Other (driveways, dropoffs)	no	no	no	no	yes	no	no	no
(slope/slide repair)	no			no			yes	no
(mailbox turnout)	yes			yes				no
Preference for using millings								
RAP	5 *	2		5				yes
Erosion control	4	5	5	2	4			
Base / Subbase	1	4	3	1		3		yes
Under Guardrail	5	3		4	5			yes
Level-up	1	1	1	3	2			yes
Ditch liner	6			4	5			
Disposal	7			5				
Other base patching			4					
shoulder	2		2	6	1	1		
pavement layer						2		
driveways					3			
Can quality of millings vary?	yes	yes	yes	yes	yes	yes	yes	yes
Reason for variation in quality	gradation, oilcontent	age of asphalt, cheap seal	gradation, type of AC	gradation, asphalt type, oil content	milling process	age, material used	contamination, age, quality of pavement	speed of milling operation, asphalt type, depth of cut
Best way to assess quality of millings	gradation and extraction tests	color, odor, particle size	strength, gradation,	gradation, oil content, moisture content,	workability	density, gradation, oil content, unconfined compression test	gradation, asphalt content, impurities, aggregate quality	gradation, density
Will the Division use millings as subbase if desired characteristics and specifications are met?	probably, but on limited scale	yes	yes	yes	presently no, but opinion may change	yes	yes, but will depend on volume of material	yes
Is Disposal of millings a problem	no	no	no	no	no	no	no	no

* Numbers indicate prioritized preference (1-highest, 7-lowest).

erosion control and ditch liner. The processed millings have been primarily used on low-volume roads. Subbase being a critical component of the pavement application of millings, coupled with the lack of specific standards is regarded by Divisions with a degree of hesitancy. However, if the desired characteristics and specifications are met, each of the Divisions has shown an interest in using millings in subbase applications. Although Division I, II, IV, VI, and VIII have been using millings for subbase, they too would like to have certain specific standards for their use. The quality of millings is an important factor when deciding for a particular use. Similar to the problems discussed in Chapter 2 and Chapter 3, the ODOT Divisions also have identified gradation, age of asphalt, type of AC, milling process, speed of milling operation, contamination, age of the stockpile, and depth of cut as the primary factors affecting the quality of millings. The speed of milling operation highly affects the quality of millings. Large chunks of millings as well as a large amount of fines (minus No. 200 sieve millings) indicate poor quality. Also, the size of millings required for shoulder applications differs from the size required for subbase applications, thereby giving rise to new complications as to what should be the optimum size. As the age of stockpile increases, compaction of millings under its own weight takes place, thereby degrading the quality of millings.

The mixture quality of processed millings varies according to its intended use. Each type of application requires a specific quality of millings and specific emulsion formulation. Obtaining the desired millings quality is a major problem because of the history of success of certain quality millings on one job/project and their failure on another. The addition of high float emulsions to the millings improve the performance, however, the amount of emulsion along with its specific additives to be added for a particular application varies.

Disposal of millings is not a problem because the millings are usually either utilized on some recycling job or are given to the contractors for disposal. Most of the Divisions give part of the millings to Counties for patching applications.

Each of the eight Divisions of ODOT has been using processed millings based upon its past experience in the use of processed millings in a variety of applications. However, the design practice followed by these Divisions cannot be termed as optimum. Rational criteria and testing methodology need to be introduced for designing the optimum and most economical mix of millings and formulated emulsion. Since subbase applications are very important, more appropriate specifications and tests will have to be developed.

Overall, it appears that each of the Divisions of ODOT has tried to make an optimum use of millings. However, due to the lack of specific standards for each of the applications, there have been some project failures. Each of the Divisions is keen in knowing the desired characteristics and specifications. All look forward to expanded uses and more successes from the cold millings from asphalt pavements.

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.

The material presented in the first phase of this report is based on a comprehensive literature search of technical reports, journal articles, and symposia proceedings in transportation engineering. The second part relates to the Oklahoma experience, namely, interviews with the personnel of the eight Divisions of ODOT and reports, if any, that were made available. This chapter summarizes the conclusions from the study with emphasis on Oklahoma and includes recommendations for future activities.

5.1 General Summary

Processed millings have been used extensively in a variety of applications like shoulders, mailbox turnouts, parking lots, level-up, and base/subbase applications all over the United States. Studies carried out by various DOTs indicate that as high as 70 percent RAP has been used in hot recycled mixtures, higher percentage than this has been restricted due to serious smoke emission problems encountered. As both cold and hot recycling have shown successes as well as failures in the past, suitability of a particular process is difficult to predict. The quality of millings is greatly affected by material variability, improper blending of millings and virgin materials, and improper drainage thereby leading to a number of project failures. The Texas study has shown that raw millings when used in projects have led to project failures due to lack of binding material and non uniform size. Certain emulsions when added to the raw millings, enhance their properties. However, the quantity and the type of emulsion to be added to the millings plays an important role as not all emulsions are found to be compatible with the millings. Addition of excessive emulsion leads to reduction of Hveem Stability, resilient modulus and tensile strength, while adding too little adversely affects the base strength. From the projects carried out in Pennsylvania, it seems that the single application of seal coat is insufficient when RAP is used in base course. This may be because the cold recycled mix is generally not adequately water and abrasion resistant. A double application of seal coat is recommended. Overall it can be seen that both processed as well as raw millings have been extensively used in a variety of applications by different DOTs, but the guidelines developed by them are purely on the basis of their past experience.

5.2 Oklahoma Summary

The eight Divisions of ODOT also carry out extensive recycling of millings and use them primarily in shoulder applications, erosion control, level-up operations and ditch liners. However, there have been certain project failures. In the past crusher run gravels have been used for rutfilling, mailbox turnouts and erosion control. Millings are found to be relatively inexpensive and more effective. Gradation, age of asphalt, milling process, speed of milling operations, age of stockpile and depth of cut primarily affect the quality of millings. However, due to lack of specific guidelines all the Divisions are hesitant in using millings in subbase applications. For the success of a particular job/project, it is therefore necessary to have certain definite guidelines/specifications for the use of millings in a variety of applications like, subbase/base, shoulders, erosion control, ditch liners, etc.

5.3 Conclusions From the Oklahoma Study

On the basis of information collected and analyzed for the Oklahoma portion of this study, the following conclusions are in order:

- All the divisions of ODOT are using millings preferably in level-up, shoulders, underguard rail, and mailbox turnouts. Division II, IV, VI, and VIII also use millings in base/subbase applications.
- Raw millings used on projects have shown unsatisfactory performance due to lack of binding materials. The majority of successes achieved on various projects have come through the use of processed millings using high float emulsions.
- The formulation of the high float emulsions (HFE 300) added to the millings depends upon the type of project in which the millings are put to use. As a result, the designing of the additive package for the correct emulsion formulation for a particular project is a critical factor.
- The quality of millings is not assessed through any specifications but gradation and extraction tests, strength, oil and moisture content, workability, density, color and odor are thought to be attributes (properties) to consider.
- Large size chunks of millings indicates inferior quality millings. The presence of coarse aggregates improves quality. Also, finer millings indicate presence of hot sand or soil asphalt thereby indicating inferior quality millings.
- The quality of millings is also believed to be highly affected by the speed of milling operations. Low speed produces better quality of millings.
- Except for Division V, all the other divisions will use millings as subbase, if desired characteristics and specifications are met.

5.4 Recommendations for Further Research.

In view of the conclusions drawn as listed above the following recommendations can be made:

- A testing methodology has to be introduced for determining the quality of millings in terms of their physical and mechanical/engineering properties.
- Since there is already acknowledged material variability, it becomes important to identify the process through which additives (type and amount) will render millings acceptable.
- Subbase application being more critical than shoulder applications, mailbox turnouts and erosion control, specifications regarding this (subbase) application need to be developed before it is used in practice.

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APPENDIX I FIELD PERFORMANCE EVALUATION

I.1 Test Sections

This chapter discusses the results of some test sections where field implementation was carried out to evaluate the performance of treated and untreated RAP. The projects are located in Texas and Pennsylvania.

I.1.1 Dallas District - McKinney Test Sections

In 1992, a field implementation project was carried out to evaluate the performance of untreated RAP and treated RAP with other commonly used maintenance mixes (Estakhri, 1994). The following materials were used in this project.

- RAP (untreated)
- Treated RAP (RAP blended in a pugmill with AES-300RP three months prior to the experiment),
- HMCL: hot mix-cold laid asphalt concrete pavement, Item 350, Type D (Standard Specifications for Construction of Highways, Streets and Bridges 1982), and
- LRA: limestone rock asphalt, Item 330, Type C (Standard Specifications for Construction of Highways, Streets and Bridges 1982)

Using these materials and combinations of these materials, six overlay sections were constructed on FM1461 in Collin County near McKinney, Texas. These six test sections were constructed end to end across both lanes of FM 1461. Each test section was 33 m (700 feet) in length and about 25 to 40 mm (1 to 1.6 inches) thick. The test sections were constructed as follows:

1) HMCL,

2) HMCL blended with untreated RAP (started with a 45/55 blend of RAP and HMCL, and later increased to 55 percent HMCL and 45 percent RAP and finally to 70 percent HMCL and 30 percent RAP),

3) HMCL blended with treated RAP (50/50 blend),

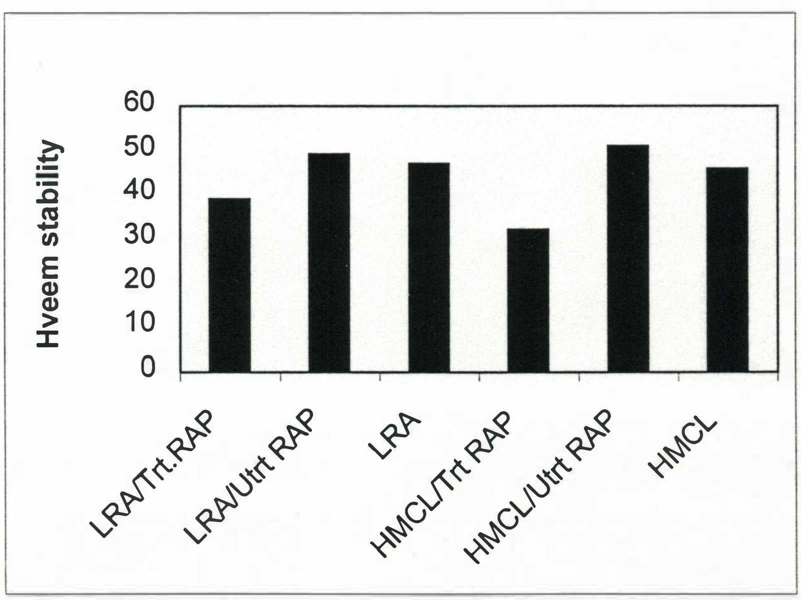
4) LRA blended with untreated RAP (60 percent LRA and 40 percent RAP),

5) LRA blended with treated RAP (50/50 blend), and

6) LRA.

Hveem stability tests were conducted for the above six mixes. The values of Hveem stability for the McKinney test section shown in Figure I.1 suggest that untreated RAP blended with LRA and HMCL gave the highest value (51), while the lowest value (32) was observed for the treated RAP blended with HMCL. The reduction in the Hveem stability of treated RAP is attributed to the higher binder content in the mix.

Figure I.1 Hveem Stability Data for McKinney Test Section Materials



Field performance of these test sections indicated that all the sections performed well. Some amount of rutting was exhibited by each of the sections, but there was no major distress. Rutting was mainly due to the underlying pavement which itself was slightly rutted prior to the application of the test sections and not due to the experimental materials.

Test section 1: HMCL

Except for one 2.5 square meter (27.25 square feet) area which was bleeding, rest of the section was found to be in excellent condition.

Test section2: HMCL/Untreated RAP

Basically this section was constructed using several proportions of the HMCL and untreated RAP materials. Initially a blend composed of 45 percent HMCL and 55 percent RAP was placed, but as the blend looked too dry and the surface appeared too rough, the remainder of the test section in the westbound lane was constructed with about 55 percent HMCL and 45 percent RAP. But, as the maintenance personnel were still not pleased with the appearance, they constructed the eastbound lane of the test section with 70 percent HMCL and 30 percent RAP.

The portion with the highest RAP percentage 45/55 ravelled quite severely within the first 24 hours after construction. However, this ravelling did not progress any further throughout the monitoring period of two years.

The 55/45 blend and the 70/30 blend of HMCL/untreated RAP were in good condition except for some slight ravelling. Almost no discernable difference was observed between the 55/45 blend and the 70/30 blend.

Test section 3: HMCL/Treated RAP Blend

Except for slight ravelling, this section performed well. This section was not particularly better than the previous section which had 55/45 HMCL/untreated RAP.

Test section 4: LRA/Untreated RAP Blend

This section performed relatively well throughout the monitoring period. It was slightly more ravelled than test section 3 and exhibited some slight cracking. It also contained a very small pothole about 100 mm (4 inches) in diameter.

Test section 5: LRA/Treated RAP Blend

The material blend used to construct this test section was composed of 50 percent LRA and 50 percent RAP treated with AES-300RP emulsion. This test section performed well with no distress noted.

Test section 6: LRA

This test section served as a control section and was constructed with 100 percent LRA. It performed very well with no distress noted.

In summary, all the test sections performed well, and there was very little difference in the performance of test sections containing treated versus untreated RAP when blended with conventional maintenance mixtures. Hence it would seem cost effective to use untreated RAP when blending with a conventional maintenance mixture. On the basis of general appearance and ride quality the test sections were classified as follows:

1) HMCL,
2) HMCL/Untreated RAP (55/45 and 70/30 blend),
3) LRA,

4) HMCL/ Treated RAP,

5) LRA/Untreated RAP, and

6) LRA/Treated RAP.

Table I.1 gives the cost, Hveem stability, and performance evaluation for the different materials used.

Table I.1 Summary of Cost, Laboratory Properties and Field Performance: McKinney Test Section

Materials Used	Cost of Finished Mixture	Hveem stability value	Performance Evaluation
LRA/Treated RAP (50/50)	$\$29.33/m^3$ (\$22.00/cy)	39	Success
LRA/Untreated RAP (60/40)	$\$25.33/m^3$ (\$19.00/cy)	49	Success
LRA (control)	$\$40.00/m^3$ (\$30.00/cy)	47	Success
HMCL/Treated RAP (50/50)	$\$20.00/m^3$ (\$15.00/cy)	32	Success
HMCL/Untreated RAP (60/40)	$\$14.13/m^3$ (\$10.60/cy)	51	Success
HMCL (control)	$\$21.33/m^3$ (\$16.00/cy)	46	Success

I.1.2 Fort Worth District - Cleburne Test Sections.

In April 1992, the construction of five research test sections (Estakhri, 1994) was undertaken to evaluate the field performance of RAP. The following materials were used for these experimental sections.

1) RAP (untreated)

2) Treated RAP (RAP blended with one percent MS-1)

3) HMCL: hot mix cold laid ACP, Item 350, Type FF (TxDOT Standard Specifications for Highways, Streets and Bridges 1982), and

4) LRA: limestone rock asphalt, Item 330, Type CC (TxDOT Standard Specifications for Highways, Streets and Bridges 1982).

Using these materials five overlay sections were constructed. Each of the sections constructed were 150 m (492 feet) in length and the material was placed about 25 mm (1 inch) thick. The test sections were constructed as follows:

1) HMCL,

2) HMCL blended with untreated RAP (70 percent HMCL and 30 percent RAP ,

3) HMCL blended with treated RAP (50/50 blend),

4) LRA, and

5) LRA blended with treated RAP (50/ 50 blend).

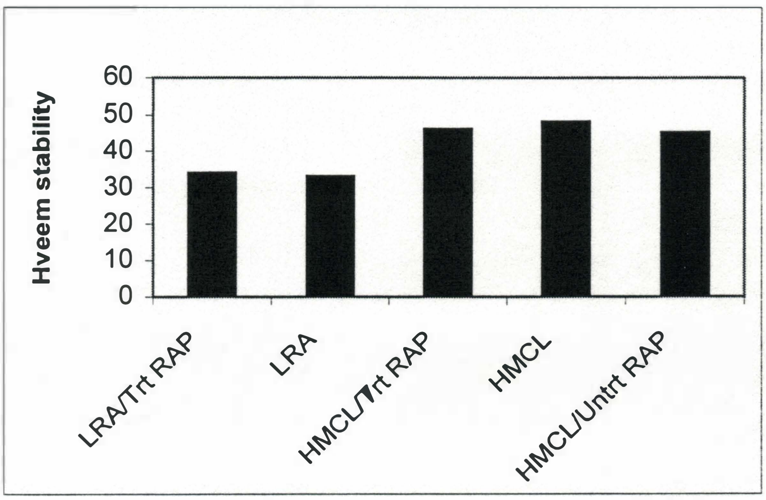
Laboratory tests were conducted for these sections. These tests were performed on laboratory molded samples obtained soon after construction The data for the Hveem stability for the Cleburne test sections are shown in Figure I.2. Referring to Figure I.2, the results show that the addition of treated RAP and RAP to the HMCL and LRA had little effect on Hveem stability.

The performances of these sections were monitored for a period of two and a half years. A description of the performance of each test section is given below:

Test section 1: HMCl

This section served as a control material and was constructed using 100 percent HMCL. This section performed better than any of the other four sections in this Cleburne experiment and showed no signs of distress.

Figure I.2 Hveem Stability Data for Cleburne Test Section Materials



Test section 2: HMCL/Untreated RAP Blend

This section was in a very good condition with the exception of some slight ravelling. However, most of this ravelling occurred immediately after construction.

Test section 3: HMCL/Treated RAP Blend

This section was in very good condition throughout the study with the exception of some ravelling. Also, the ravelling occurred immediately after the construction and did not progress throughout the monitoring period.

Test section 4: LRA

This section served as a control material and was constructed of 100 percent LRA. It exhibited severe longitudinal cracking and significantly more ravelling than sections 1,2 and 3. Generally, this type of pavement failure evidenced in the surface would be associated with a subgrade failure. However, in this case the cracking appeared only in the surface material only. The surface overlay was very thin (25mm or one inch) and in some places the cracks were wide enough to see the underlying pavement layer which was not cracked. The pavement did not exhibit this type of distress beyond the experimental sections and it was believed that there was slippage between the surface layer and underlying pavement which caused these types of cracks. This section was the worst of the 5 sections in Cleburne.

Test section 5: LRA/Treated RAP Blend

This test section also exhibited a significant amount of ravelling, though not as severe as that in section 4. In this case, it appeared that the addition of the treated RAP to the LRA actually improved its performance. The addition of emulsion to the RAP may have increased the overall binder content of the blend, thereby improving its cohesive properties. Table I.2 gives the summary of cost, Hveem stability and performance evaluation for the Cleburne test sections.

In summary all the HMCL test sections performed well, however neither of the LRA sections performed acceptably, the primary distress concern being the significant cracking. In general, it seemed that LRA was a drier mix than HMCL, which led to this type of slippage cracking. It appeared that a heavier tack coat might have improved the performance of the LRA test sections.

Table I.2 Summary of Cost, Laboratory Properties and Field Performance: Cleburne Test Section

Materials used	Cost of finished mixture	Hveem stability value	Performance evaluation
LRA/Treated RAP (50/50)	Not Available	34	Failure (cracking)
LRA (control)		33	Failure (cracking)
HMCL/Treated RAP (50/50)		46	Success
HMCL (control)		48	Success
HMCL/Untreated RAP (70/30)		45	Success

I.1.3 Childress District - Childress Test Section

In August 1992 RAP was mixed with four different emulsions: AES 300RP, CRR-60, ARE-68, and MS-1 (Estakhri, 1994). The ARE-68 blend was placed as a thin (50mm or 2 inches) overlay section on US 287. The other three blends were used in routine maintenance throughout the district. Only the ARE-68 blend was monitored in this study. The quantities and costs for Childress RAP blends are presented in Table I.3.

Hveem stability tests conducted on the four blends showed that the AES-300RP modified RAP had the lowest stability. Figure I.3 shows that MS-1 modified RAP exhibited the highest stability value (21) and AES-300RP the lowest value (6). The ARE-68 treated RAP exhibited rutting soon after construction. By the end of two years, the rutting was about 12-19 mm (0.5-0.75 inches) which was attributed to inadequate density achieved in the compacted mixture. At same time some signs of flushing indicated that there might have been an excessive amount of binder in the mix. Table I.4 includes the summary of cost, laboratory properties and field performance for the Childress test section.

Table I.3 Quantities and Costs for Childress RAP Blends

Type Emulsion Used	Quantity by Emulsion, % by wt.of RAP	Quantity RAP Recycled, m^3	Cost, Recycled Material, per m^3
AES-330RP	2 1/2	2,201	$20.28
CRR-60	3 - 3 1/2	836	$32.36
ARE-68	3 - 3 1/2	836	$33.09
MS-1	3 - 3 1/2	1,001	$22.80

Figure I.3 Hveem Stability Data for Childress Test Section Materials.

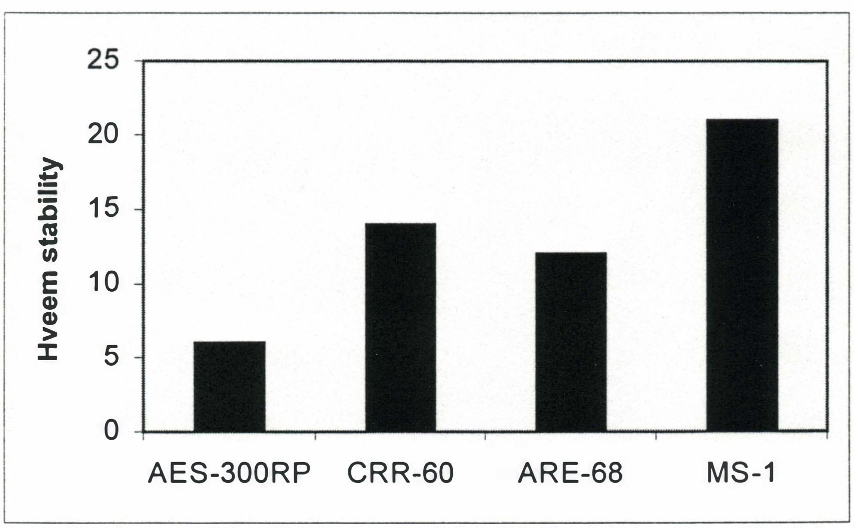


Table I.4 Summary of Cost, Laboratory Properties and Field Performance: Childress test section

Materials Used	Cost of finished mixture	Hveem stability value	Performance evaluation
RAP with 2 1/2 % AES-300RP	$ 20.28/m^3 ($15.21/cy)	6	NA
Rap with 3-3 1/2 % CRR-60	$ 32.36/m^3 ($24.27/cy)	14	NA
Rap with 3-3 1/2 % ARE-68	$ 33.09/m^3 ($24.82/cy)	12	Marginal success (rutting)
RAP with 3-3 1/2 % MS-1	$22.80/m^3 ($17.10/cy)	21	NA

I.1.4 Brownwood District - Routine Maintenance Treatments

The routine maintenance treatments using milled asphalt treated with AES-300RP were observed by the Texas Transportation Institute (TTI) in July 1991 (Estakhri, 1994). The routine maintenance treatments included: (1) the intersection to a county road, (2) a level-up to correct a pavement dip, and (3) a base repair.

Hveem stability test was conducted on RAP treated with AES-300RP. The Brownwood RAP blend had a Hveem stability of 18. District personnel felt the treated RAP contained excessive asphalt binder; hence, for the base repair, the treated RAP was blended with one-third untreated RAP prior to placement. The performance of these sections was monitored for a period of three years. The intersection to the county road showed slight ravelling, but rest of the section performed well. The level-up and base repairs were surfaced with a chip seal within the first year of the monitoring study; however, they both performed well with no signs of distress.

I.1.5 Tyler District - Kilgore Test Sections

In September 1992, the district maintenance constructed two thin overlays to be evaluated as test sections in this study (Estakhri, 1994). Two 24 m (500 feet) test sections were placed on FM 2011 in Rusk County near Kilgore. These test sections were constructed as follows:

1) Treated RAP (RAP blended with 2 percent AES- 300RP) and
2) HMCL: hot mixed-cold laid ACP, Item 350, Type D (TxDOT Standard Specifications for Highways, Streets and Bridges 1982).

Hveem stability tests were conducted on laboratory molded samples of Kilgore RAP treated with AES-300RP as sampled in field. The Hveem stability value being low could not be measured. The low value of Hveem stability was attributed to the excess amount of binder in RAP. The performance of these sections was monitored for a period of two years. The description of the performance is presented in the following:

Test section 1: Treated RAP

This section showed serious signs of flushing and rutting in the wheelpaths and by the end of the second year, about 70 percent of the area was flushed and ruts were as deep as 25 mm (1 inch).

Test section 2: HMCL

This section was constructed as a control using HMCL. This test section performed well except for some flushing in the wheelpaths of the eastbound lane.

Thus the treated RAP section performed poorly as predicted by the extremely low Hveem stability values. The poor performance is mainly because of the excess amount of binder added to RAP. The HMCL test section performed acceptably despite some minor flushing.

I.1.6 Yoakum District - Base Repair

In July 1992, RAP was used to repair a base failure on FM 609 in Fayette County (Estakhri, 1994). A pavement recycler was used to repair this base failure. Some amount of new base material was also added so that more gradual slope could be provided at the edge of the pavement for better side support. The pulverized mixture was stabilized using lime. The cross section of the pavement repaired was as follows:

1) 90 mm (3 1/2 inches) of Hot Mix ACP.
2) 150 mm (6 inches) of crushed stone base.
3) 60 mm (2 1/2 inches) of ACP.

No laboratory test was performed on this material. Throughout the study, the base repair performed very well with no visible sign of distress. The surface was sealed after one year as part of a routine chip seal operation.

I.1.7 Houston District - Base Reconstruction

In October 1992, cement stabilized RAP was used to construct the base of a parking lot at the district office (Estakhri 1994). The RAP material was stockpiled near the district office where it was blade-mixed with Type II cement by maintenance personnel. The RAP was placed and compacted in three lifts for a total thickness of eight inches. It was then surfaced with Item 340, Type D, hot-mix asphalt concrete pavement. The maintenance supervisor reported that if the base had not been constructed with the

RAP, the material of choice would have been Item 292, asphalt stabilized base. The cost of labor, equipment and materials for construction of the RAP base was $9,330 ($18.66 per cubic yard or $24.55 per cubic meter). The estimated cost of labor, equipment and materials to construct the parking lot base using Item 292 was $11,644 ($30.64 per cubic meter or $23.29 per cubic yard).

No laboratory test was conducted on this material. A large part of this parking lot around the perimeter appears to be used for storage of materials such as pipes, drums of paint, and 5-gallon cans of patching material. The parking lot as a whole performed well except for the development of some minor cracks at some places. The base reconstruction project in the Bryan District also performed very well throughout this study. There was a small area near the intersection of FM 980 and SH 19 that exhibited some rutting and shoving. The remainder of the pavement had minor rutting (less than 6mm or 1/4 inch), but the overall performance was good. Table I.5 gives the summary of cost, laboratory properties, field performance for Brownwood district, Tyler district and Houston district.

I.1.8 Chester County Project

The Gum Tree Road in Chester County near Philadelphia, Pennsylvania had a lot of patches and alligator cracking indicating a poor base (Kandhal and Koehler, 1987). The existing road was milled to depth of 75 mm (three inches) using a Roto Mill and the millings were discharged into the Midland Motopaver. The RAP was mixed with two percent CMS-2 emulsion. The recycled mix was laid to give a compacted base course of 125 mm (five inches) thick. Several weeks after the road was opened to traffic, it was overlaid with 37.5 mm (1-1/2 inch) of hot mix. The road was completed in 1980. Study conducted in1987 showed that road performed very well although it carried a lot of truck traffic. Widening of the road was also carried out during the recycling process.

Table I.5 Summary of Cost, Laboratory Properties, Field Performance:Brownwood District, Tyler District, Yoakum District, Houston District

Field Experiment	Materials Used	Cost of finished mixture	Hveem stability value	Performance evaluation
Brownwood district	RAP with 2% AES-300RP	$20.48/m^3$ ($15.36/cy)	18	Success
Tyler district	RAP with 21/2% AES-300RP	Not available	0	Failure (rutting)
	HMCL	$17.33/m^3$ ($13.00/cy)	Not available	Success
Yoakum district	Lime stabilized RAP	$3.41/m ($2.83/sy) In-place cost	Not applicable	Success
Houston district	Cement stabilized RAP	$24.88/m ($18.66/cy) In-place cost	Not applicable	Success

I.1.9 Susquehanna County Projects

Five in-place recycling projects totaling 166 miles were completed in 1983. A Bros reclaimer, which pushes the emulsion, was used in these projects (Kandhal and Koehler, 1987). About 2-3 percent CMS-2 emulsion was added to the RAP. The lack of sufficient moisture content made it difficult to disperse this small amount of emulsion in RAP. Hence a water tanker was brought to raise the moisture content of the RAP to about 3-5 percent. As the compacted, recycled base course appeared to be very dense, initially it was covered with a single application of seal coat. The surface was good in some sections, but, when the single seal coat was lost, potholes were developed. This showed that a double application of seal coat is required as the cold recycled mix is generally not adequately water and abrasion resistant. After two years of service, the three projects were patched and a double surface treatment was applied. The road was found to perform better after the treatment.

I.1.10 Luzerne County Project

In 1983 an in-place recycling project (Kandhal and Koehler, 1987) was completed in Luzerne County on Legislative Route 40060. The existing road was narrow, badly cracked, and heavily patched, and had an unsatisfactory cross section. Using a Raygo Barco Mill, the existing roadway was milled and recycled to a depth of 75 mm (3 inch). RAP was mixed with CSS-1h emulsion. Unlike the Susquehanna County Project, this section was performing well upto 1984 even though it had a single seal coat. However, after two years, potholes had appeared on the roadway, indicating the need for another application of seal coat. Inspection indicated that after three years the section in which 100 percent RAP was used has more potholes than the section in which a 50/50 blend of RAP and virgin aggregate was used.

I.1.11 Mercer County Project

An in-place recycling project (Kandhal and Koehler, 1987) was completed in Mercer County on Traffic Route 208 in May 1985. The material was milled using a CMI milling machine and passed over a 25-37.5 mm (1-1 1/2 inch) scalping screen. The oversized material was fed into the crusher by a conveyor to reduce its size. The milled material was mixed with about three percent CSS-1h emulsion and recycled to a depth of

75mm (three inch). The gradation of the RAP on this project was significantly finer than the laboratory generated RAP. Due to the high amount of average daily traffic, the base course was overlaid with 87.5mm (3-1/2 inches) hot mix overlay. The recycled pavement was inspected after one year and was found to perform satisfactorily.

I.2 Inference from Test Sections

Most of the test sections discussed in the prior section have performed well, even though there have been certain failures. Careful study of all the test sections discussed above indicates that the most common problem faced with treated RAP was the addition of excessive amounts of emulsion. Treated as well as untreated RAP blended with HMCL was consistently successful in 6 applications (Estakhri, 1994) placed throughout the state of Texas. Also, the RAP maintenance mixture evaluated in this study which had Hveem stability greater than 24 performed successfully. RAP seems to perform successfully and is also cost effective when used as a stabilized base and/or blended with HMCL at ratios of 60/40 (HMCL/Untreated RAP), while the treated RAP was blended with HMCL at ratios of 50/50. But no appreciable difference was noticed in the performance of these blends. Hence for the project to be more cost effective, it seems that the blend of HMCL and untreated RAP (60/40) would be better.

From the projects carried out in Philadelphia, it seems that the single application of seal coat is insufficient when RAP is used as a base course. This may be because the cold recycled mix is generally not adequately water and abrasion resistant. A double application of seal coat is recommended.

APPENDIX II QUESTIONNAIRE

ASPHALT MILLING

PROBLEM STATEMENT: Asphalt millings in Oklahoma are not entirely consumed in producing recycled asphalt pavements . From environmental and other considerations, it is desirable to find alternate use for these materials. It is possible that millings may have some structural benefit as a subbase material; however , no good data regarding the structural strength, integrity, permeability, or suggested lift thickness is currently available. Also, there may be other uses of asphalt millings such as erosion control, ditch/channel liner, and level-up against the shoulder.

PROPOSED RESEARCH: Collect information/data from a literature search and interviews of pertinent people from each field division in ODOT, as well as collect millings samples. Conduct appropriate laboratory tests, subsequently, to determine the character and suitability of using asphalt millings as a structural subbase element. Also, determine the permeability, structural, and other characteristics for pavement applications and other uses.

ANTICIPATED BENEFITS: Provide a specification for the use of asphalt millings in subbases or other applications.

FIELD VISIT QUESTIONNAIRE

Interviewed on:

People present:

How many asphalt milling operations do you have in your Division? Where are they located?

How much milling materials (approximately) were produced (in tons) in each of these operations in 1996? How much in 1995, 1994, 1993, and 1992?

How much (in tons) of the asphalt millings produced in 1996 were used in recycled pavement or other applications (please specify category and corresponding amounts)? What were the corresponding amounts for 1995, 1994, 1993, and 1992?

How are asphalt milling materials used in your Division? (Please check blocks that apply)

- ☐ **Pavement Layer** ☐ **Base/subbase** ☐ **Under Guardrail**
- ☐ **Erosion Control** ☐ **Level-up/ Shoulder-up**
- ☐ **Ditch/Channel Liner** ☐ **Other (please specify)**

How would you prefer to use millings? (Please specify rank from 1 to t 8)

- ☐ **As RAP** ☐ **Base/subbase** ☐ **Level-up**
- ☐ **Erosion control** ☐ **Under Guardrail** ☐ **Ditch Liner**
- ☐ **Disposal** ☐ **Other (please specify)**

Does it appear to you that the quality of millings can vary significantly? If "yes" why?

What is the best way to assess the quality of millings? Please specify.

Would it be worthwhile to you to know the strength, stability and other characteristics of millings for possible use in subbase? If "yes" what characteristics would you consider important?

Would your Division use millings as subbase, if the desired characteristics and specifications were available?

Is disposal of millings a problem in your Division? If "no" could it become a problem in the near future?

Any other information you would like to provide pertaining to potential use of millings.