193

National Cooperative Highway Research Program

NCHRP Synthesis 193

Hot In-Place Recycling of Asphalt Concrete

A Synthesis of Highway Practice

TE
7
.N26
no.
193

Transportation Research Board
National Research Council

TE
7
.N26
no.
193

SPORTATION RESEARCH BOARD EXECUTIVE COMMITTEE 1994

---31225 SEP 2 3 2004

ı M. SUSSMAN, *JR East Professor and Professor of Civil and Environmental Engineering, Massachusetts Institute of Technology*

ıair

N C. LIBURDI, *Director, Port Authority, The Port Authority of New York and New Jersey*

ve Director

AS B. DEEN, *Transportation Research Board, National Research Council*

Members

BRIAN J. L. BERRY, *Lloyd Viel Berkner Regental Professor & Chair, Bruton Center for Development Studies, University of Texas at Dallas*
DWIGHT M. BOWER, *Director, Idaho Department of Transportation*
JOHN E. BREEN, *The Nasser I. Al-Rashid Chair in Civil Engineering, The University of Texas at Austin*
KIRK BROWN, *Secretary, Illinois Department of Transportation*
DAVID BURWELL, *President, Rails-to-Trails Conservancy*
L. GARY BYRD, *Consulting Engineer, Alexandria, Virginia*
A. RAY CHAMBERLAIN, *Executive Director, Colorado Department of Transportation* (Past Chair, 1993)
RAY W. CLOUGH, *Nishkian Professor of Structural Engineering, Emeritus, University of California, Berkeley*
RICHARD K. DAVIDSON, *Chairman and CEO, Union Pacific Railroad*
JAMES C. DELONG, *Director of Aviation, Stapleton International Airport, Denver, Colorado*
DELON HAMPTON, *Chairman & CEO, Delon Hampton & Associates*
DON C. KELLY, *Secretary and Commissioner of Highways, Transportation Cabinet, Kentucky*
ROBERT KOCHANOWSKI, *Executive Director, Southwestern Pennsylvania Regional Planning Commission*
JAMES L. LAMMIE, *President & CEO, Parsons Brinckerhoff, Inc.*
WILLIAM W. MILLAR, *Executive Director, Port Authority of Allegheny County, Pennsylvania* (Past Chair, 1992)
CHARLES P. O'LEARY, JR., *Commissioner, New Hampshire Department of Transportation*
JUDE W. P. PATIN, *Secretary, Louisiana Department of Transportation and Development*
NEIL PETERSON, *former Executive Director, Los Angeles County Transportation Commission*
DARREL RENSINK, *Director, Iowa Department of Transportation*
JAMES W. VAN LOBEN SELS, *Director, California Department of Transportation*
C. MICHAEL WALTON, *Ernest H. Cockrell Centennial Chair in Engineering and Chairman, Department of Civil Engineering, The University of Texas at Austin*
DAVID N. WORMLEY, *Dean of Engineering, Pennsylvania State University*
HOWARD YERUSALIM, *Secretary of Transportation, Pennsylvania Department of Transportation*
ROBERT A. YOUNG III, *President, ABF Freight Systems, Inc.*

MIKE ACOTT, *President, National Asphalt Pavement Association* (ex officio)
ROY A. ALLEN, *Vice President, Research and Test Department, Association of American Railroads* (ex officio)
ANDREW H. CARD, JR., *President and CEO, American Automobile Manufacturers Association*
THOMAS J. DONOHUE, *President and CEO, American Trucking Associations* (ex officio)
FRANCIS B. FRANCOIS, *Executive Director, American Association of State Highway and Transportation Officials* (ex officio)
JACK R. GILSTRAP, *Executive Vice President, American Public Transit Association* (ex officio)
ANA S. GUTIERREZ, *Acting Administrator, Research and Special Programs, U.S. Department of Transportation* (ex officio)
CHRISTOPHER HART, *National Highway Traffic Safety Administrator, U.S. Department of Transportation* (ex officio)
ALBERT J. HERBERGER, *Maritime Administrator, U.S. Department of Transportation* (ex officio)
DAVID R. HINSON, *Federal Aviation Administrator, U.S. Department of Transportation* (ex officio)
GORDON J. LINTON, *Federal Transit Administrator, U.S. Department of Transportation* (ex officio)
JOLENE M. MOLITORIS, *Federal Railroad Administrator, U.S. Department of Transportation* (ex officio)
RODNEY E. SLATER, *Federal Highway Administrator, U.S. Department of Transportation* (ex officio)
ARTHUR E. WILLIAMS, *Chief of Engineers and Commander, U.S. Army Corps of Engineers* (ex officio)

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Transportation Research Board Executive Committee Subcommittee for NCHRP
JOSEPH M. SUSSMAN, *Massachusetts Institute of Technology* (Chair)
A. RAY CHAMBERLAIN, *Colorado Department of Transportation*
FRANCIS B. FRANCOIS, *American Association of State Highway and Transportation Officials*
LILLIAN C. LIBURDI, *Port Authority of New York and New Jersey*
RODNEY E. SLATER, *Federal Highway Administration*
L. GARY BYRD, *Consulting Engineer*
THOMAS B. DEEN, *Transportation Research Board*

Field of Special Projects
Project Committee SP 20-5
KENNETH C. AFFERTON, *New Jersey Department of Transportation*
ROBERT N. BOTHMAN, *H.E.L.P.*
JOHN J. HENRY, *Pennsylvania Transportation Institute*
GLORIA J. JEFF, *Michigan Department of Transportation*
EARL SHIRLEY, *Consulting Engineer*
JON UNDERWOOD, *Texas Dept. of Transportation* (Chair)
WILLIAM A. WESEMAN, *Federal Highway Administration*
J. RICHARD YOUNG, JR., *Mississippi Department of Transportation*
RICHARD A. MCCOMB, *Federal Highway Administration* (Liaison)
ROBERT E. SPICHER, *Transportation Research Board* (Liaison)

Program Staff
ROBERT J. REILLY, *Director, Cooperative Research Programs*
CRAWFORD F. JENCKS, *Manager, NCHRP*
LOUIS M. MACGREGOR, *Administrative Officer*
STEPHEN E. BLAKE, *Senior Program Officer*
LLOYD R. CROWTHER, *Program Officer*
AMIR N. HANNA, *Senior Program Officer*
FRANK R. MCCULLAGH, *Senior Program Officer*
KENNETH S. OPIELA, *Senior Program Officer*
DAN A. ROSEN, *Senior Program Officer*
SCOTT A. SABOL, *Program Officer*
EILEEN P. DELANEY, *Editor*

TRB Staff for NCHRP Project 20-5
ROBERT E. SKINNER, JR., *Director for Studies and Information Services* SALLY D. LIFF, *Manager, Synthesis Studies* STEPHEN F. MAHER, *Senior Program Officer* LINDA S. MASON, *Editor*

National Cooperative Highway Research Program

Synthesis of Highway Practice 193

Hot In-Place Recycling of Asphalt Concrete

JOSEPH W. BUTTON, DALLAS N. LITTLE,
and CINDY K. ESTAKHRI
College Station, Texas

Topic Panel

FRANK M. BEDNAR, *Federal Highway Administration*
JAMES L. BURATI, JR., *Clemson University*
FREDERICK D. HEJL, *Transportation Research Board*
DENNIS A. MORIAN, *Pennsylvania Department of Transportation*
ELVIN E. ROUSSEAU, *Texas Department of Transportation*
KEVIN D. STUART, *Turner-Fairbank Highway Research Center*
JACK VAN KIRK, *California Department of Transportation*

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1994

Subject Areas
Pavement Design, Management and Performance
Materials and Construction

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 193

Project 20-5 FY 1989 (Topic 21-10)
ISSN 0547-5570
ISBN 0-309-05324-2
Library of Congress Catalog Card No. 94-076360

Price $16.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to highway administrators; pavement designers, materials, research, maintenance and specification engineers; and others interested in economical methods for reconstructing or rehabilitating asphalt concrete pavements. It describes the processes and equipment used for hot in-place recycling (HIPR) of asphalt concrete and provides information on mix designs, performance, and guidelines for effective use. A significant amount of the information provided is based on the current practices of state highway agencies.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

With increased public demand to conserve natural resources, minimize disruption of traffic flow during construction, and practice efficient expenditure of funds for highway maintenance, hot in-place recycling of asphalt concrete pavements is receiving a renewed interest among those involved with the reconstruction or rehabilitation of asphalt concrete pavements. This report of the Transportation Research Board describes the various practices in use for HIPR of asphalt concrete in the United States and Canada, including HIPR processes and equipment, HIPR as a tool for asphalt pavement rehabilitation, mixture design for HIPR processes, HIPR case histories, relative performance of HIPR pavements, and guidelines for the effective use of HIPR.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Joseph W. Button, P. E., Consulting Engineer; Dallas N. Little, Research Engineer and Head, Materials and Construction Division, Texas Transportation Institute; and Cindy K. Estakhri, Texas Transportation Institute were responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Frank M. Bednar, Highway Engineer, Federal Highway Administration; James L. Burati, Jr., Professor, Department of Civil Engineering, Clemson University; Frederick D. Hejl, Engineer of Materials and Construction, Transportation Research Board; Dennis A. Morian, Structural Materials Division, Bureau of Construction & Materials, Pennsylvania Department of Transportation; Elvin E. Rousseau, Assistant District Engineer, Texas Department of Transportation; Kevin D. Stuart, Research Highway Engineer, Federal Highway Administration Turner-Fairbank Highway Research Center; and Jack Van Kirk, Senior Materials & Research Engineer, California Department of Transportation.

The Principal Investigators responsible for the conduct of this synthesis were Sally D. Liff, Manager, Synthesis Studies and Stephen F. Maher, Senior Program Officer. This synthesis was edited by Linda S. Mason.

Scott A. Sabol, Program Officer, National Cooperative Highway Research Program, Transportation Research Board, provided valuable assistance to the consultants, the topic panel and staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

HOT IN-PLACE RECYCLING OF ASPHALT CONCRETE

SUMMARY

Hot in-place recycling (HIPR) is defined as a process of correcting asphalt-pavement surface distress by softening the existing surface with heat, mechanically removing the pavement surface, mixing it with recycling agent, possibly adding virgin asphalt or aggregate, and replacing it on the pavement without removing the recycled material from the original pavement site. The Asphalt Recycling and Reclaiming Association (ARRA) recognizes three basic HIPR processes: heater-scarification, remixing, and repaving. HIPR may be performed as either a single-pass or a two-pass procedure.

Heater-scarification typically scarifies about 25 mm (1 in.), more or less, of the existing road surface, rejuvenates it, and reshapes it in the final operation. A conventional wearing course is normally placed over the recycled pavement immediately or some time later. This is sometimes referred to as a two-pass operation. The repaving process is similar to this but the overlay is placed simultaneously with the recycled layer in a single pass. The remixing process combines many of the same elements as heater-scarification but includes the added element of incorporating and blending virgin material in a moving mixer and then laying it as a wearing course. HIPR typically scarifies no more than 25 to 50 mm (1 to 2 in.) but has been performed at scarification and milling depths up to 75 mm (3 in.).

Most types of surface distress in an asphalt pavement can be corrected by HIPR provided the pavement has adequate structural integrity. Types of pavement distress that may be addressed include rutting, corrugations, raveling, flushing, loss of surface friction, minor thermal cracking, and load-associated cracking. The remixing process can even address the source of the distress when it is caused by characteristics of the aggregate in the surface mix. Hot milling usually eliminates degradation of the recycled aggregate.

During HIPR, there can be considerable gaseous emissions from heating and mixing equipment. This has caused concern about air pollution, particularly in urban areas; however, major advancements toward reduced emissions have been made in recent years.

HIPR is acceptable to the driving public because of increased awareness of the need to conserve natural resources—and with HIPR drivers can see the old pavement virtually turn into a new pavement. Single-pass HIPR causes only a relatively small disruption in traffic flow when compared with other modes of pavement rehabilitation. In urban areas, recycling offers pavement rehabilitation without the expensive and time-consuming task of repositioning drains, curbs, manholes, overpasses, shoulders, and other height-sensitive structures.

The bottom line, of course, is comparative cost. Published information suggests that, when all factors are considered, a savings up to 35 percent can be achieved when a 25-mm (1-in.) HIPR layer is compared with cold milling and placement of a new 25-mm overlay. HIPR eliminates the costs associated with stockpiling, handling, hauling, and inventorying reclaimed asphalt pavement (RAP). Additional cost savings can be realized

by the reduced interruptions in traffic flow when compared with conventional rehabilitation techniques.

Careful consideration must be given to preparing specifications that are relevant to the intended construction program. Specifications must clearly describe an acceptable finished HIPR product. In some cases, it may be necessary to describe certain elements of the equipment required to furnish the desired product.

A telephone survey of all 50 state highway agencies was conducted to determine the extent of use of HIPR and type of processes being used. The survey revealed that fewer than 10 state agencies are using HIPR routinely. Most states have tried HIPR but only experimentally. Many states have no experience with the new remixing processes.

Research is needed to provide an overall physical characterization of in-place recycled hot mix as compared with conventional hot mix. Life-cycle costs (first costs, life cycles, required rehabilitation periods, and maintenance alternatives) for HIPR should be better defined and compared with other maintenance and rehabilitation alternatives. Comprehensive guidelines for the overall HIPR process need to be developed to aid pavement engineers in the decision-making process. HIPR is a technology that has seen rapid changes in the last several years; this synthesis, therefore, represents the best information available at the time of publication.

CHAPTER ONE

INTRODUCTION

The first asphalt pavement was placed in the United States in 1870 (*1*). By 1915, reuse of asphalt pavements in road structures was recognized as an important option for pavement rehabilitation (*2*). However, use of asphalt cement to stabilize recycled asphalt pavement probably dates back only to the 1930s or 1940s (*3,4*). This time period also saw the development of the first heater-planer machines. Thus, recycling of asphalt pavements has been practiced in the United States for a long time. However, the total quantity of pavement materials recycled by all methods from 1915 to 1975 is small in comparison to the amount that has been recycled since 1975 (*5*).

Early recycling efforts were somewhat primitive and equipment wear and tear from pulverizing old asphalt concrete was considered excessive and costly. Equipment and technology have improved, and productivity has increased to a degree that recycling of asphalt concrete by a variety of procedures is increasingly attractive to highway engineers and should be even more attractive to those responsible for selecting construction alternatives (*6*). Today, asphalt-pavement recycling is commonly performed on highways and airport runways using several methods, including both hot and cold methods for both central plant and in-place recycling. Of these four methods, the most sweeping changes and innovations in North America in the last 10 years have been in hot in-place recycling (HIPR).

The scope of this synthesis is limited to HIPR of asphalt pavements. HIPR is defined as a process of correcting asphalt-pavement surface distress by softening the existing surface with heat, mechanically removing the pavement surface, mixing it with recycling agent, possibly adding virgin asphalt or aggregate, and replacing it on the pavement without removing the recycled material from the original pavement site. HIPR may be performed as either a single-pass operation that recombines the restored pavement with virgin material, or as a two-pass operation, wherein the restored material is recompacted and the application of a new wearing surface then follows a prescribed interim period.

The Asphalt Recycling and Reclaiming Association (ARRA) was founded primarily on the principle of hot surface recycling and has rapidly expanded to represent nearly every form of pavement recycling (*7*). The ARRA recognizes three basic HIPR processes (*8,9*):

1. Heater-Scarification—heating, scarifying, rejuvenating, levelling, reprofiling, compacting;
2. Repaving—heating, scarifying, rejuvenating, levelling, laying new hot mix, reprofiling, compacting; and
3. Remixing—heating, scarifying, rejuvenating, mixing (and/or adding new hot mix), mixing, levelling, reprofiling, compacting.

All three methods are sometimes referred to as surface recycling. Heater-scarification typically removes up to 25 mm (1 in.) of the existing road surface, rejuvenates it, and reshapes it in the final operation. The repaving process includes recycling to an approximate 25-mm (1-in.) depth, adding a recycling modifier to improve asphalt viscosity, and simultaneously applying a thin overlay over the recycled layer. The remixing process incorporates and blends virgin material with recycled material in a pugmill and then lays the blended material as a wearing course. Sometimes scarification is replaced or assisted by milling. These processes are discussed in detail in Chapter Two.

As a result of relatively recent developments in Europe, Japan, and the United States, HIPR is experiencing a metamorphosis. Heater-scarification process and some older repaving processes (particularly the multiple-pass methods) are being replaced by the newer single-pass repaving or remixing processes. The majority of published information available on long-term performance of HIPR is on heater-scarification and multiple-pass repaving methods because these types of HIPR have been in use for the longest period of time (*4*).

Incentives for asphalt-pavement recycling are stronger in some countries than in the United States, primarily because relatively higher population density has forced more emphasis on land and resource management. As an example, in the Netherlands, some 2 million tons of reclaimed asphalt pavement (RAP) are available annually as compared with 7 million tons of new hot-mix asphalt. All this RAP will be reused because (1) a shortage of mineral aggregate exists in several European countries, including the Netherlands, (2) disposing of RAP in a Dutch waste dump costs more than purchasing virgin hot-mix asphalt, and (3) European environmental laws prohibit the unregulated dumping of RAP.

Use of landfills for dumping commercial waste is being strongly discouraged in some states. For example, landfill-use fees in some states, such as Minnesota and New Jersey, are quite high—thus discouraging disposal of RAP and encouraging recycling.

A nationwide survey of the state Departments of Transportation (DOTs) was conducted to determine the extent of use of HIPR and types of processes being used. The survey revealed that only about 20 percent of the state DOTs are using HIPR routinely. Sixty-five percent have tried HIPR but most only experimentally. Many states have no experience with the new remixing processes. Results of this survey are described in detail in Chapter Three.

CHAPTER TWO

HOT IN-PLACE RECYCLING PROCESSES AND EQUIPMENT

Certain preparatory measures are common to all three of the HIPR methods. Before recycling, major defective portions of the pavement surface are normally leveled to provide a satisfactory working platform, and large depressions indicating base failures are repaired. Field and laboratory tests are performed to determine the type and amount of recycling agent needed to restore more desirable asphalt rheological properties and, if appropriate, the type and amount of new hot mix or virgin materials.

Recent improvements in HIPR equipment and procedures have significantly expanded its application. Machinery and procedures vary with different paving contractors and equipment manufacturers, but HIPR falls into one of the three process categories mentioned above. These processes, which are recognized by the ARRA, are discussed in some detail in the following paragraphs. They are presented in order of increasing degree of sophistication of equipment and techniques and in chronological order of their development.

Although certain problems are noted in this chapter, solutions to these problems are usually determined on a case-by-case basis; no universal solutions exist. Specific problems and example solutions are given in Chapter Five.

HEATER-SCARIFICATION

Heater-scarification is sometimes referred to as reshaping. It is an outgrowth from equipment developed by Gibbons and Reed Contractors of Salt Lake City in the 1930s (*10,3,7*). Heater-scarification has been in fairly common use in the United States since the mid 1960s, but in the 1970s it began transforming to the more versatile processes described in subsequent subsections (*11*). Compared with the later developments in HIPR, heater-scarification is a rather simple process involving heating of the old pavement surface, scarifying using a bank of non-rotating teeth, adding a liquid rejuvenating additive (recycling agent), mixing and leveling the recycled mix using a standard auger system, then compacting it using conventional equipment (Figure 1). No new aggregate materials are added. A scarification depth of 19 mm to 25 mm (.75 in. to 1 in.) is common (*6,12*) although 50 mm (2 in.) can be achieved. Because of differences in hardness of different portions of a pavement, scarification may not always produce a smooth, flat, excavated surface.

Early heating methods used direct contact of the flame with the pavement surface. Later developments have moved toward radiant or infrared heating to reduce damage to the asphalt cement and undesirable visible emissions (*13,1,15*). Most heaters currently use indirect heating and propane gas as fuel (*4*). Heating is performed by one or more machines, providing there are at least two banks of heaters on one machine or two single heaters traveling in tandem, producing a temperature in the scarified material of 110°C to 150°C (230°F to 302°F) (*12,16*). The heated pavement is scarified by leveling rakes (two or three horizontal rows of spring-loaded or breakaway scarifier teeth or tines), which are normally in alignment with the finished pavement surface to ensure a uniform thickness of recycled mix layer. The nonrigid or spring-loaded mounting is also helpful in allowing the scarifier to pass over road obstacles such as manhole covers or concrete patches (*4*) and minimizes tensile fracture of the underlying asphalt-pavement structure. Long-term oxidative aging of the old pavement plus the small amount of heat aging during recycling may result in a relatively hard asphalt cement. To restore flexibility to the pavement, recycling agents are added during processing or within 8 hours after compaction to restore, as nearly as possible, the original properties of the asphalt.

Heater-scarification is used to eliminate surface irregularities and cracks and restore the pavement surface to the original (or at least a desirable) line, grade, and typical cross-section to ensure proper drainage. Normally, only limited and short-term improvements in skid resistance are possible. Heater-scarification has demonstrated success in reducing reflective cracks when used prior to placement of a new hot-mix asphalt overlay (*5*); however, this is not always the case. The bond between an old pavement and a new hot-mix asphalt overlay is also improved by use of the heater-scarifier immediately before the overlay. Multiple heaters may be necessary to allow the heat to penetrate a seal coat (*12*). Heater-scarification alone is limited in its ability to repair rough-riding or severely rutted roads, neither is it effective in significantly increasing a pavement's load carrying capacity (*16*).

Heater-scarification is often followed by a conventional asphalt-concrete overlay. When the overlay is placed as a separate operation, this HIPR process is referred to as the two-pass method.

REPAVING

Heater-scarification, when followed closely by conventional overlay paving, is known as a multiple-pass repaving process. A schematic of this process is shown in Figure 2.

The single-pass repaving process of HIPR was invented by Earl Cutler as a pavement patching strategy in the late 1950s. In the mid 1960s, he redesigned his equipment and manufactured the first repaver machine to heat and rework the surface of an existing pavement while at the same time applying a thin layer of new hot-mix asphalt (*17*). The repaving process consists of the following steps: heating, scarifying and/or rotary milling, applying a rejuvenating agent, mixing rejuvenator with scarified material, placing the recycled mixture as a leveling course using primary screed, and simultaneously placing a new hot-mix wearing course (*17*). In Figure 3, the first five steps are shown to be identical to the heater-scarification process. Figure 4 depicts a typical repaving process and associated equipment.

In the first step of the recycling process, heat is applied to the surface of the existing pavement through forced air or radiant heating systems at a temperature of approximately 190°C (374°F).

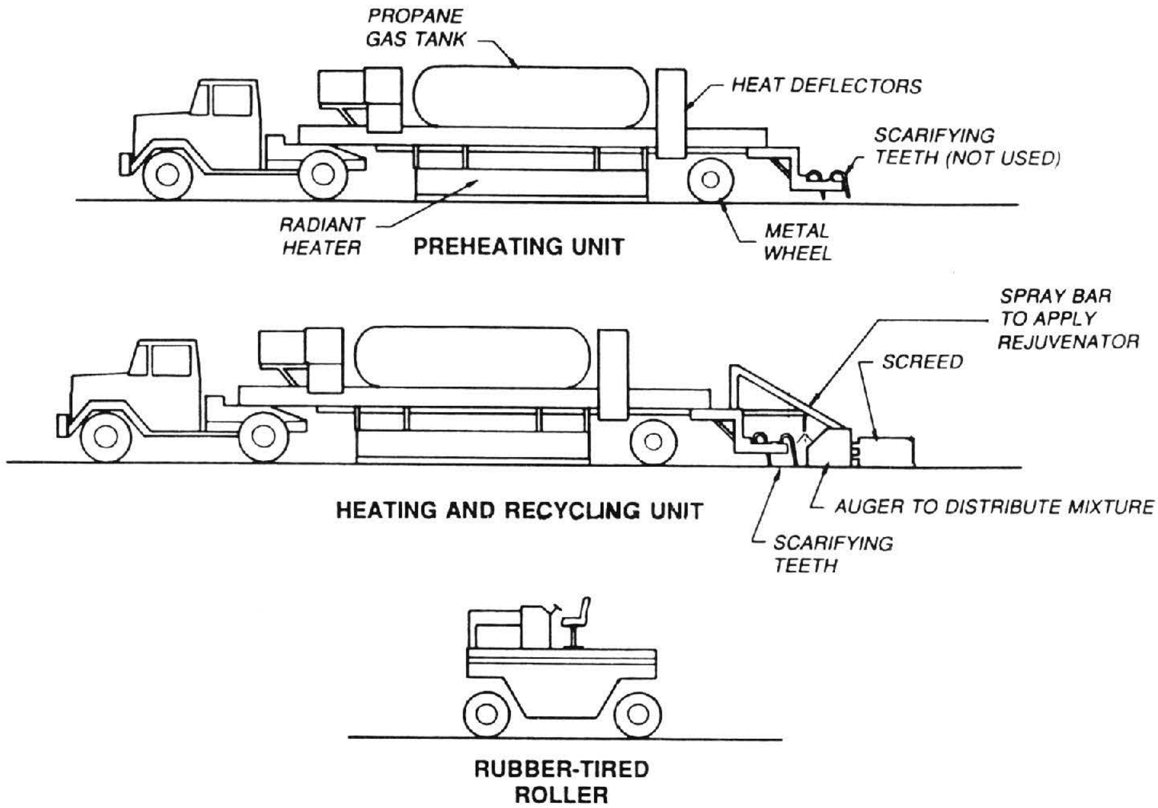

Figure 1 A basic heater-scarification process. (After *4*)

Heating softens the existing pavement to a depth of 22 mm to 29 mm (0.9 in. to 1.2 in.). The heated, softened pavement, in a plastic condition, allows rows of carbide-tipped teeth to scarify the pavement in a level plane to a depth of 19 mm to 25 mm (.75 in. to 1 in.) during the second step. In one system, the scarifier teeth, mounted in staggered formation in 1-ft sections, may be individually controlled by air-actuated diaphragms that allow each section to be pressed into the pavement to ensure adequate depth. Some systems allow the scarifier teeth to be raised individually to scarify around manhole covers and such obstacles.

In the third step, an asphalt recycling agent is dispersed onto the scarified material at a predetermined rate. The application rate can be geared to the forward movement of the machine to ensure a constant rate per unit weight of RAP.

In the fourth step, the rejuvenated RAP is gathered by a blade and then moved transversely into a center windrow by means of an auger-type cross conveyor, which mixes and coats the RAP particles with the rejuvenator. In the fifth step, additional transverse augers mix and spread the recycled material in front of the recycling screed, which distributes and partially compacts it into a leveling course. In the sixth and final step, new hot-mix asphalt is conveyed from the hopper through the system to the finishing screed where it is placed (as in a conventional paving machine) while the recycled layer is still approximately 104°C (219°F). Final compaction of both layers of material immediately behind the screed is performed using conventional equipment and procedures. This ensures the creation of a monolithic bond between the new and the recycled layer (*17*).

Screeds used by most of the current HIPR processes range from those with no automatic control of grade, slope, or depth to those completely automated. For screeds with no automatic control, depth of placement is normally controlled by taking depth measurements by hand and manually adjusting the screed. Many of the automatic screeds are equipped with vibrators to achieve some initial compaction. Several single-pass machines are equipped with two screeds, one trailing the other and each individually fed, allowing multiple lifts to be placed in a single pass (*4*). The first screed places the recycled mixture and the second screed finishes the surface of the thin overlay.

Repaving may be used when heater-scarification alone cannot restore the pavement's necessary surface requirements (friction or smoothness) or when a conventional operation to place an additional thick overlay is not needed or is impractical. Application of a very thin overlay (say, 13 mm or .5 in.) with the repave process can make it economically feasible to use very expensive, high-quality aggregate that provides good, long-term skid resistance. Such an operation could extend the economically allowable haul distance for these high-quality aggregates plus preserve these precious resources when used in thin surface layers. Overlays less than 25 mm (1 in.) are not normally placed using conventional hot paving processes.

REMIXING

Remixing is used when repaving alone cannot impart the required properties to the recycled asphalt mixture and additional mineral aggregate is needed to provide adequate strength or stabil-

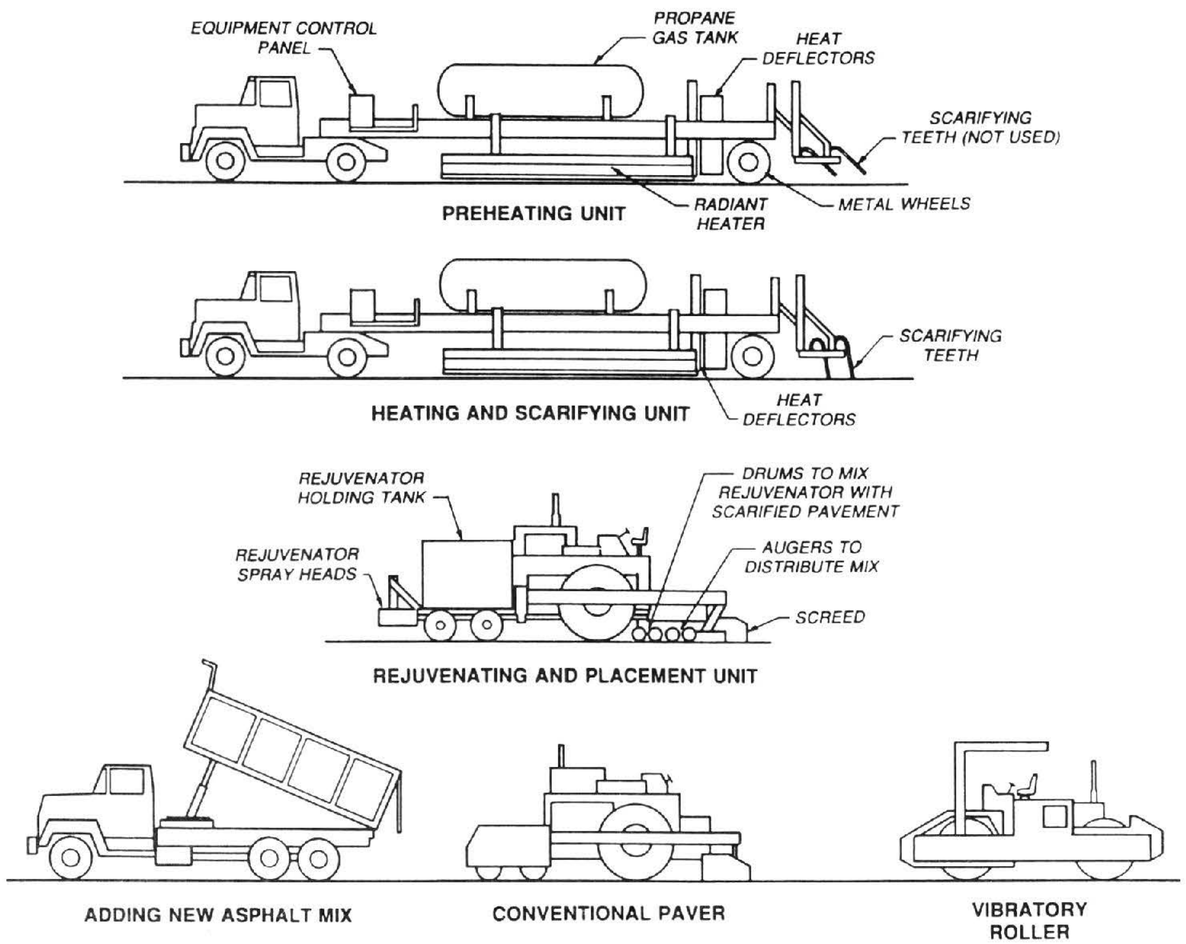

Figure 2 Multiple-pass repaving process (Dustrol). (After *4*)

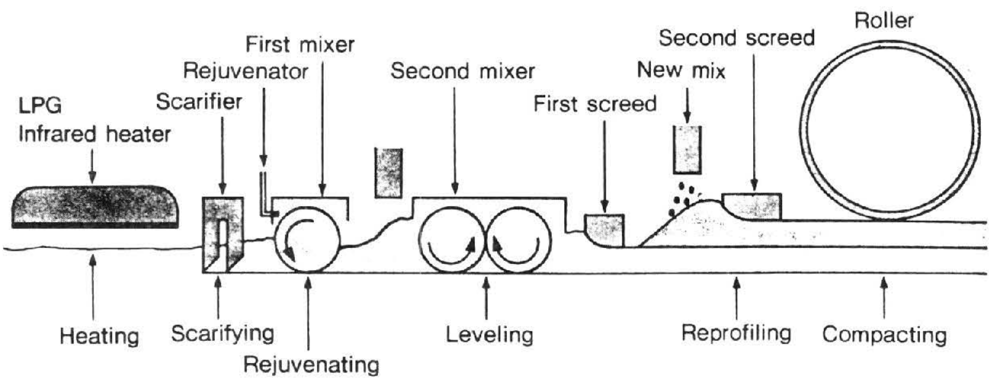

Figure 3 Repave method. After the old existing asphalt pavement materials are mixed with rejuvenator and/or new asphalt mixture, new hot asphalt mixture is overlaid, leveled, and compacted as in conventional overlaying process. (Courtesy of Taisei Road Construction Company)

ity. The single-pass remixing process was introduced in the United States around 1980.

Although there are variations, the typical remixing process begins, like the two other methods, with heating and softening of the damaged pavement by a series of infrared pre-heaters. Scarifiers or milling heads then loosen the softened material, which is augered toward the center of the machine. Then it is carried into a pugmill mixer, where it is combined with an asphalt rejuvenator and a measured quantity of virgin aggregate or hot-mix asphalt. Sometimes the rejuvenator is applied in advance of the pugmill to provide good dispersion and maximize mixing time in the loosened mix. Emulsions are typically used in all three HIPR processes to

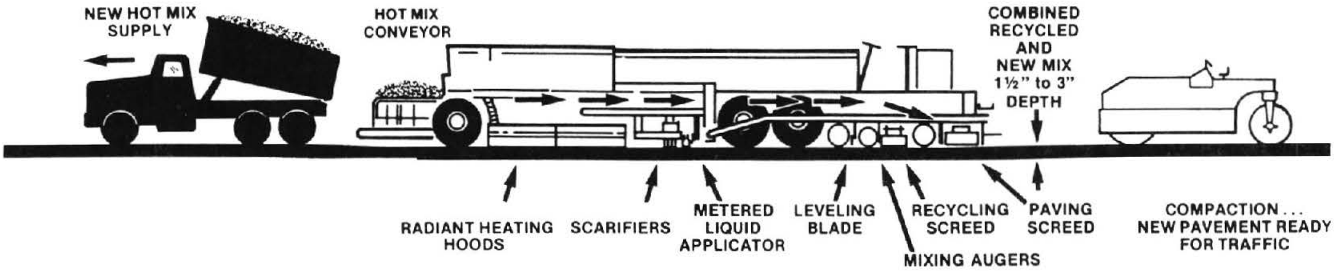

Figure 4 Single-pass repaving process. (Courtesy of Cutler Repaving, Inc.)

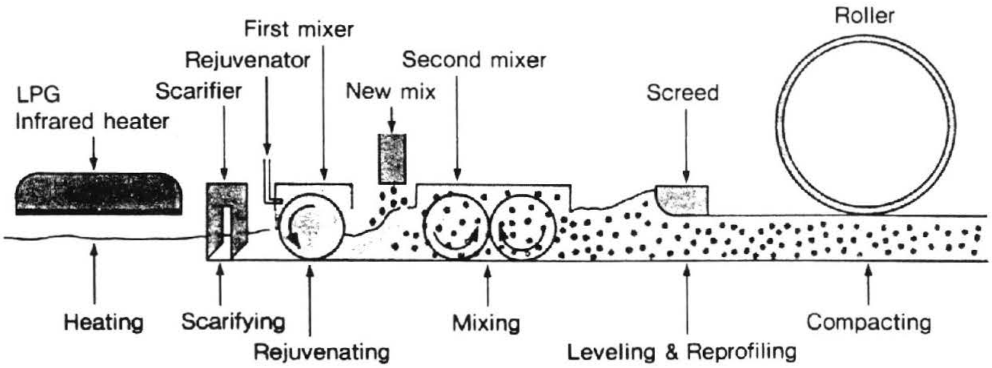

Figure 5 Remix method. The existing old pavement is heated, scarified, and mixed with rejuvenator and/or new hot asphalt mixture, then leveled and compacted while it is hot. (Courtesy of Taisei Road Construction Company)

provide a higher fluid content and thus ensure adequate dispersion of the recycling agent throughout the RAP. Finally, the resulting mixture is placed by a compacting screed and finished in the normal manner (*18,19,20,21,22*).

A schematic of one remixing process is given in Figure 5. Equipment typically used in the remixing process is illustrated in Figure 6. One to three preheaters (depending on air/surface temperature) first raise the pavement temperature to about 85°C to 104°C (185°F to 219°F) (*23*). Each preheater may cover a 12-m length of a full lane. The remixing process continues to heat the pavement, keeping it warm as the scarifiers approach.

Scarification may be accomplished using stationary tines; sometimes these are followed by (or replaced by) rotating milling heads. The pavement is typically scarified to a depth ranging from 25 mm to 38 mm (1 to 1.5 in.), although more than 50 mm (2 in.) can be achieved. In Canada, where soft asphalts are normally used, two machines in tandem have achieved depths up to 75 mm (3 in.) (*20*). Heat penetration and allowable milling depth will depend on the composition of the pavement and will vary from job to job and within a given pavement.

Trucks dump virgin hot-mix asphalt into a hopper at the front end of the remixing process. The new material is conveyed back through the machine to a storage hopper. From there it is metered into the pugmill along with the rejuvenated RAP. Although mixing of the RAP and virgin material has been attempted using only the milling heads, the most successful remixing processes incorporate a pugmill for uniform and complete mixing of the virgin materials with the RAP. In fact, some owner agencies specify a pugmill for the remixing process to ensure complete and uniform mixing of the RAP and the virgin materials.

The milled material is immediately mixed with the recycling agent and the new materials and deposited onto the roadway in a windrow. A set of augers spreads the material, then a vibrating, tamping screed places and partially compacts the blend. As placed, the pavement is typically about 110°C to 120°C (230°F to 250°F) with a temperature on the newly exposed surface receiving the overlay of about 66°C (150°F) (*24,25*). Compaction is performed using conventional equipment and procedures.

Roads with one seal coat are remixable; in fact, one seal coat can help because it is incorporated with the whole mixture and softens the recycled binder. Multiple seal coats, however, can create smoke and fire at the surface and act as an insulator against heating of the underlying pavement (*23,24*).

Since the remixing process typically uses only 16 to 30 kg/m^2 (42 to 80 lb/yd^2) of new material, fewer haul trucks are required than for conventional overlaying operations. This results in a shorter lane closure time and less disruption to the public (*26*). The use of these small amounts of virgin mixture by a relatively slow-moving paving train requires a hot-mix producer willing to supply a small amount of mixture that is often unsuitable for routine paving operations. This sometimes presents problems for the remixing contractor.

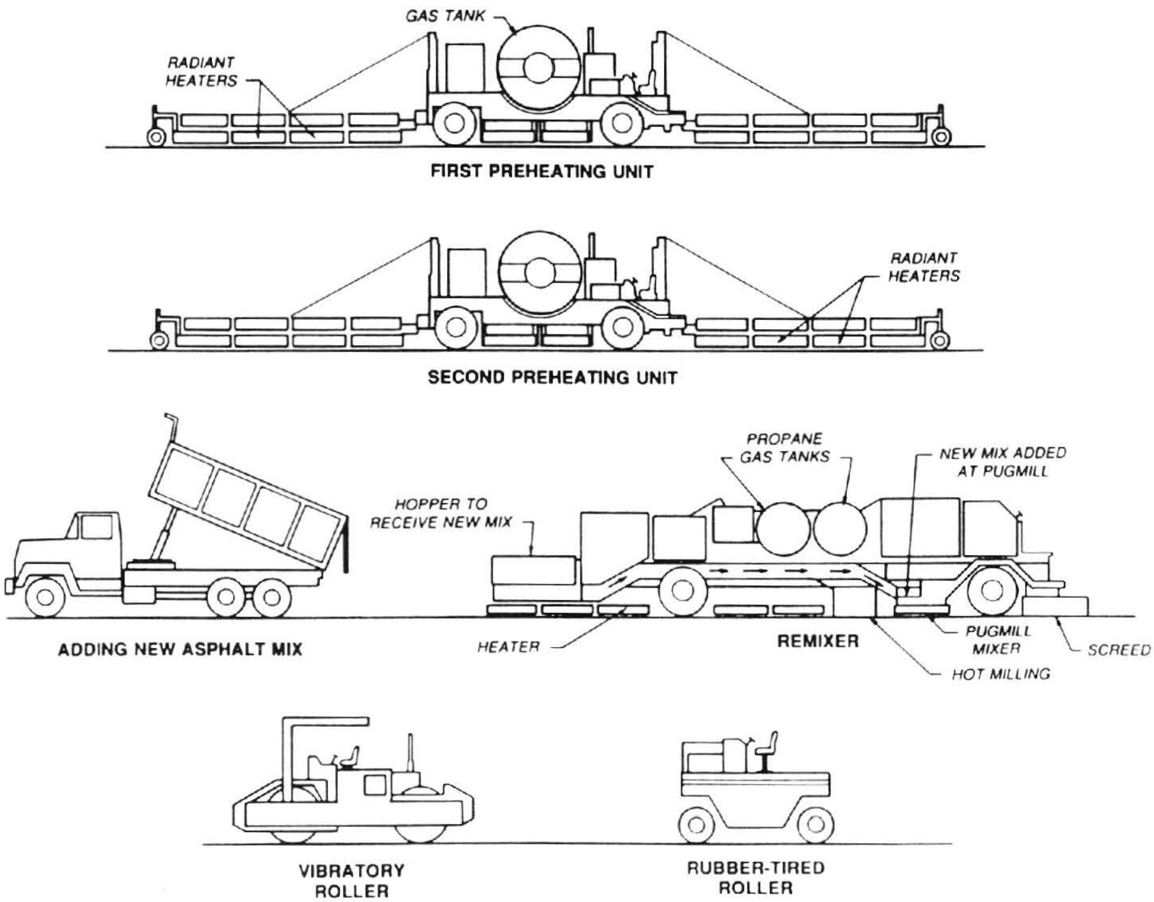

Figure 6 Single-pass remixing process. (After *4*)

RECENT DEVELOPMENTS

Microwave Heating

Microwave heating for recycling asphalt mixtures was introduced to the industry in the early 1980s and has developed rapidly since that time (*27*). A complete in-place recycling process that incorporates microwave heating is under development by Cyclean, Inc. Testing of a prototype device is expected to begin in 1993. In the prototype process design, the existing pavement is cold-milled to a maximum depth of 75 mm (3 in.). The millings are collected and conveyed to a conventionally heated pre-dryer where substantial heating occurs, final heating by the microwave unit brings the temperature to approximately 132°C (270°F). Then the mixture is placed and compacted using conventional paving and compaction equipment. The microwave system permits the addition of recycling agents and other additives as well as virgin aggregate. The process is depicted in Figure 7.

Cold milling is used because it costs less than hot milling. With the cold milling process, there is concern about degradation of the aggregate, particularly about the production of excess material less than 75 μm (No. 200 sieve).

In other research, in situ microwaving of pavements in California has shown that heat penetrates more rapidly and more deeply into the pavement than with other surface heaters such as direct flame and infrared. The temperature within the pavement rises uniformly. However, the microwaves often penetrate deeper than necessary and thus some energy is wasted. Improvements are being made to concentrate the microwave energy near the pavement surface to enhance the heating rate and conserve energy (*28,29*).

Incorporation of Tire Rubber

In October 1991, Cutler Repaving, Inc. used reclaimed tire rubber to modify a standard emulsified asphalt for the purpose of applying the modified emulsion to the hot, reclaimed material produced in its normal recycling operation. This experimental work was performed on two streets within the city limits of McAllen, Texas to determine the feasibility of applying and mixing a crumb-rubber additive into the hot recycled material, in advance of a thin overlay, thereby forming a stress-relieving membrane interlayer. The initial results from this test section confirm the feasibility of adding a crumb rubber-modified emulsion to the recycle material. Comparative performance of the test and control pavements will be monitored. Other field tests are planned.

A comprehensive laboratory evaluation of the process has also

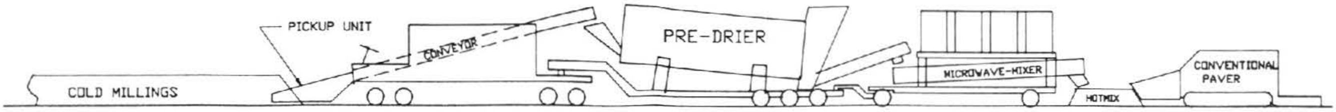

Figure 7 Single-pass process using cold milling and microwave heating to recycle 100 percent of the milled pavement. Rejuvenating agent is added in the microwave-mixer to restore the aged asphalt to a specified consistency. (Courtesy of Cyclean)

been conducted (*30*). Continuous mixing in a specially designed tank to keep the rubber particles suspended in the emulsified asphalt appears promising.

Warm Mix

The recently developed warm mix method uses a Wirtgen cold milling machine and a Marini asphalt recycle travelplant (ART) (*31*). These machines create a recycled plus virgin material (normally used as a base layer) at 77°C (170°F). The process is exactly the same as the HIPR process with one difference. It uses a lighter weight standard asphalt such as AC-5 to rejuvenate the old asphalt and coat any needed new stone.

A warm mix project begins by using a chip spreader to spread hot (130°C or 265°F) virgin materials produced by the ART on the surface of a full-lane project immediately ahead of the milling machine. A full-lane cold-milling machine cuts the existing pavement and mixes the hot virgin materials at the same time. The resulting windrow of warm recycle material has just enough virgin material to bring the grading curve back into standard specification. Work proceeds at much greater rates of tonnage than hot mix, because the temperature does not need to be elevated to hot mix levels. Because a water-based emulsion is not used, there is no break or cure time requirement. As soon as the material is compacted and cools to ambient temperature, it can be opened to traffic. It may then be overlaid at a later time.

Emission Control System

Pyrotech Asphalt Equipment Manufacturing Company has developed an emission control system which greatly reduces gaseous hydrocarbon and particulate emissions from its HIPR equipment. The system essentially collects and incinerates vapors and smoke emanating from the heated asphalt paving mixture. Pavement heating units and heater-milling units are each equipped with emission control systems.

A shroud covers areas where vapors and smoke are generated and vacuum ducts pull the gaseous effluents into a large direct-flame afterburner where combustible materials are incinerated to produce mostly carbon dioxide and water vapor. The afterburner is designed to eliminate or reduce the opacity, odor, irritants, and fallout of the effluent to levels required for compliance with air pollution standards.

The process has successfully met emission standards during operations in Idaho, Montana, and Oregon. In the fall of 1992, the system was operated in Washington and in California, which has comparatively strict emissions regulations.

CHAPTER THREE

HIPR AS A TOOL FOR ASPHALT PAVEMENT REHABILITATION

HIPR is a valuable instrument in the tool chest of the highway maintenance engineer. It offers some significant advantages in the cost-effective rehabilitation of certain major thoroughfares. Benefits and limitations of HIPR are described here. This chapter also summarizes the findings of a telephone survey of all 50 states regarding their application of HIPR.

REASONS FOR USING HIPR

HIPR can be used to correct most types of pavement surface distress and even address the source of the distress when it is due to the components of the surface mixture. According to the ARRA, types of pavement distress that may be addressed include rutting, corrugations, thermal cracking, raveling, flushing, and loss of surface friction (*32*). However, large low-frequency undulations of the pavement surface are difficult to eliminate using HIPR. New equipment capabilities often permit the source of the distress to be eliminated by the addition of asphalt rejuvenators, new asphalt, new aggregate, and other additives. In urban areas, HIPR offers a pavement rehabilitation alternative where drains, curbs, manholes, overpasses, shoulders, and other height-sensitive structures may cause problems for other rehabilitation processes.

The bottom line, of course, is comparative cost. Published information from 1981 to 1991 suggests that, when all factors are considered, a savings up to 35 percent can be achieved when a 25-mm (1-in.) HIPR layer is compared with cold milling and placement of a new 25-mm (1-in.) overlay (*3,4,14,23,33–35*). HIPR eliminates the costs associated with stockpiling, handling, and inventorying RAP (*18*). Since trucking of materials is drastically reduced, comparative cost of HIPR can be particularly attractive when long haul distances would be involved for conventional paving materials. In many instances, additional cost savings can be realized because interruptions in traffic flow are less than with conventional rehabilitation techniques. Comparative cost of HIPR is considered in Chapter Six.

When a pavement would typically need a minimal overlay to correct rutting, oxidation and/or cracking, all three HIPR processes are viable options (*36*). Rutted or cracked asphalt pavements with problems limited to the top 38 mm (1.5 in.) are ideal candidates for HIPR.

Since a very thin overlay of new material can be placed using the repave process, this process permits the cost-efficient use of high-grade (and high-cost) special aggregates that may otherwise be impractical from an economic standpoint. For example, a 13-mm (.5-in.) repaved layer might consist of a premium aggregate that provides exceptional skid resistance. The minimum thickness for a conventional overlay is about 25 mm (1 in.). In addition, repaving enables the recycling of material that is otherwise unsuitable, for example, an old wearing course containing highly polishable mineral aggregates. Cold milling of asphalt concrete may significantly alter the grading of the aggregate by producing excessive fines. Hot milling, on the other hand, virtually eliminates degradation of the recycled aggregate.

With recent developments, excellent control of the mean viscosity of the asphalt in the recycled mixture is now achievable. The rejuvenator feed rate should be controlled automatically by the forward movement of the machine, and this factor should be included in HIPR specifications. Use of microwaves to supplement heating of the recycled mixture helps minimize asphalt hardening and reduces emissions.

HIPR is acceptable to the driving public because of increased awareness of the need to conserve natural resources and because drivers can see the old pavement virtually turn into a new pavement. An important reason for selecting single-pass HIPR is the relatively small disruption in traffic flow compared with other modes of pavement rehabilitation. This is due to shorter construction time, shorter construction trains, and fewer haul trucks. Since the material is replaced immediately, motorists do not have to contend with a dropoff between lanes (*37*). Compact modern machinery allows adjacent highway lanes to be kept open to traffic.

LIMITATIONS OF HIPR

The HIPR process should be limited to pavements with adequate load-bearing capacity since only the uppermost 25 mm to 50 mm (1 in. to 2 in.) are reconditioned and only modest additions to pavement thickness can normally be achieved. When in doubt, base strength should be evaluated using deflection measurements. Roads that have structural deficiencies, requiring additional material, should not be subjected to HIPR unless a design to accommodate the needed strength is incorporated into the process. Old asphalt pavements with obvious base failures, irregular and frequent patching, and in need of major drainage improvements are not suitable candidates for in-place recycling (*38*). (See Figures 8 through 11.)

Although HIPR processes have been reported to treat asphalt pavements to a maximum depth of 75 mm (3 in.) (*4*), 38 mm to 50 mm (1.5 to 2 in.) is the typical maximum. Maximum depth is determined by hardness of the asphalt and the insulating quality of the pavement layer.

Roads suitable for HIPR should have a minimum of 75 mm (3 in.) of hot-mix asphalt in place. Thinner asphalt surfaces may be torn apart and broken loose from the base by the horizontal shear stresses of the banks of scarification teeth. If surface cracks extend to the base, they can be covered temporarily, but they will reappear. Unless traffic can be rerouted, very narrow roads are not good candidates for HIPR since the machines are large with working widths from 3.3 to 4.8 m (10 to 14.5 ft). Streets with numerous

Figure 8 An old asphalt pavement that has surface cracks but has maintained good structural integrity is suitable for hot in-place recycling.

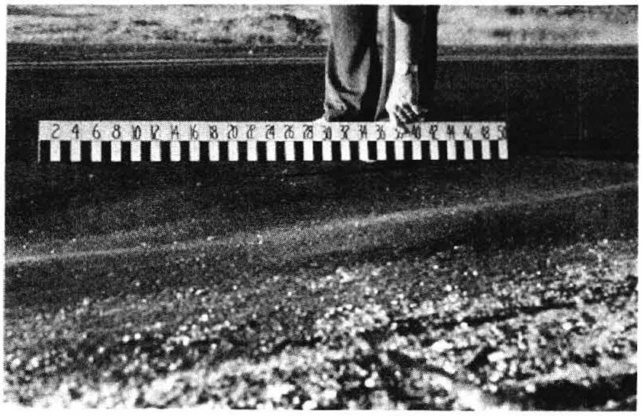

Figure 11 HIPR can be used to eliminate ruts and possibly ameliorate mixture deficiencies causing the problem, if in the uppermost 2 inches.

Figure 9 Ride quality of this pavement may be restored by HIPR but removal of excessive crack sealer may be required in some areas.

Figure 10 A patchwork surface will cause difficulty in controlling mixture design during HIPR and, therefore, may be an unsuitable candidate.

metal appurtenances (such as manholes) are not recommended for HIPR.

As with all hot-mix asphalt paving operations, the preferred weather is hot, calm days with no moisture in or on the existing pavement. Under good operating conditions, the remix-repave process can advance at rates of up to 5 lane-m/min (15 lane-ft/min) (*9*). Heating capability controls forward progress; width of pass has little effect. Some state DOT specifications require the equipment to be capable of covering a minimum of 3.1 lane-m/min (9.4 lane-ft/min) (*39*) or even 6.1 lane-m/min (18.7 lane-ft/min) at a scarification depth ranging from 13 mm to 19 mm (.5 in. to .75 in.) (*40*). Night or early morning operations during cold weather can have significant adverse effects on rate of coverage and, in fact, reduce coverage below these specified levels (*41*). With street work that involves utility covers or poor ambient conditions, the production rate can drop to less than 500 m^2/hr (*9*).

A seal coat or slurry seal on the surface of an asphalt pavement acts as a heat insulator during HIPR. The chip seal itself heats rapidly but it also retards the heat from penetrating into the underlying asphalt pavement (*12*). Some have recommended that multiple seal coats be planed and removed in advance to allow proper heat transfer to underlying material (*3,42*).

Surface courses with aggregate larger than 25 mm (1 in.) in diameter may be unsuitable for current HIPR processing equipment.

There are two potentially limiting environmental factors that require consideration and improvement: occasional considerable gaseous emissions (blue smoke) must be controlled through equipment modifications and/or changes in operation procedures, and the rejuvenators typically used must meet increasingly strict health and safety requirements (*39*). Early HIPR equipment and operators had problems controlling excessive heat and smoke during recycling operations. This caused consternation among transportation officials and generated many complaints from air quality officials. Indirect heating methods and special emission control systems have successfully addressed many of these problems. HIPR can now be used even in urban areas where air pollution is a major concern.

HIPR equipment is inherently complex and constructed in such a way that many of the operations that occur in the field cannot be readily observed or inspected. Therefore, certain elements of quality control during construction will be the responsibility of the contractor. Specifications must deal with those items that can be monitored and should be in the end-result or performance-based categories.

PROCESS SELECTION GUIDELINES

The following is given to aid the reader in selecting the most appropriate HIPR method for a particular need:

Particular Need	HIPR Process
Restore surface irregularities (ruts, corrugations, etc.)	All
Reestablish crown and drainage	All
Eliminate surface cracking	All
Temporarily close reflection cracks	All
Rework pavement without substantially raising grade	All
Rejuvenate oxidized pavement surface	Heater-Scarification
Place new overlay in a single-pass operation	Repave
Restore surface friction	Repave, Remix
Modify aggregate grading or quality in existing pavement	Remix
Rejuvenate without overasphalt existing mixture with additional recycling agent	Remix

SURVEY OF STATE DOTS

A telephone survey was conducted to determine the extent of HIPR use by state DOTs. Normally the state materials engineer or state bituminous engineer was contacted. Most of the survey results are summarized in Table 1. These findings should be considered subjective since they represent the opinions and knowledge of a single individual. (See Appendix A for the questionnaire used to guide the survey.)

Research reports on HIPR and case studies were requested of those states that had any available. The reports pertinent to this study are discussed in Chapter Five.

Use of HIPR by State DOTs

In general, HIPR has been used by state DOTs on a very limited basis. Of the 50 states surveyed, 18 have not used HIPR at all. Many of these states reported that they would like to try HIPR, but the opportunity has not arisen. Reasons some states are not using HIPR are cited below:

- HIPR equipment and operators are not located in our area.
- Most of our surfaces are open graded and are not suitable candidates for HIPR.
- Pressure from the hot-mix industry to use all new material is so strong, HIPR has been suppressed.
- We considered HIPR once for a 50-mm (2-in.) thick pavement, but it would have required placing the material in two lifts. For pavements 50 mm (2 in.) thick or more, it's cheaper to do central plant recycling.
- HIPR could only be cost-effective for use on interstate highways, and we do not believe the quality of HIPR is adequate for interstates.
- We don't know very much about HIPR and have no data on the process to assess cost-effectiveness.
- We are not impressed with HIPR mainly because we feel that the process burns the asphalt.

Twenty-two states reported using HIPR but only on an experimental basis. Ten additional states use HIPR on a somewhat regular basis but generally on fewer than five jobs per year. None of the states commonly use HIPR on more than five jobs annually. Collectively, these 32 states have used at least one of the three HIPR processes. Thirteen states reported having used heater-scarification; several others have probably used the process but did not consider it recycling. Fifteen states reported having used repaving, and 16 states reported having used remixing.

Most states did not specify a preference in HIPR methods, but of the nine states that did, all indicated a preference for the remixing process. This preference is primarily because of this method's added option of incorporating additional aggregate to correct deficiencies in the recycled mixture. One state reported that both heater-scarification and remixing have their place depending on the pavement condition: heater-scarification can be used only if the pavement is structurally sound while remixing can improve both structural and binder properties.

HIPR is used primarily on major and secondary highways. Some states commonly place a surface seal or overlay on the HIPR pavement, but this can depend on the specific circumstance. For example, Montana places an overlay on the HIPR pavement if it is on an interstate highway. Both Louisiana and Ohio construct an overlay if heater-scarification was the HIPR process used.

None of the agencies surveyed reported recycling of asphalt-rubber pavements by HIPR or any other method.

Comments on Mixture Design Procedures

Mixture design procedures for HIPR pavements are not well established. Some states allow the contractor to specify the mixture design or to submit a mixture design that will bring the surface back in compliance with the state specifications. Many states, as a minimum, take cores of the candidate pavement to determine in-place properties: binder content and viscosity, as well as aggregate grading. Based on the hardness of the binder, a rejuvenator may be specified at a quantity needed to soften the existing binder to the desired degree. Few states reported the use of any additives or admixtures with HIPR except when the remixing process was used.

If virgin aggregate is to be added to the recycled pavement, standard mixture design procedures will normally be used to develop a mixture that meets appropriate state specifications.

Only 17 states reported considering a structural value for HIPR pavements. Fourteen of these considered the structural value of a HIPR pavement layer about the same as virgin hot-mix asphalt. Three indicated they assigned it a structural value of slightly less than virgin hot-mix asphalt.

Comments on Quality Control Procedures

Few states reported well-established procedures for maintaining quality control during HIPR. The contractor is often required to

TABLE 1
RESULTS OF U.S. SURVEY ON HOT IN-PLACE RECYCLING

State	Extent of HIPR Use			Methods Used			Milling Depth Range, in.	Written Specs Available	Class of Highways for HIPR			Surface Seal or Overlay Common Placed Over HIPR Pavement	Performance of HIPR Pavements				Comments
	None	Experimental	≤5jobs/yr	Heater Scar.	Repave	Remix			Major	Secondary	Low Volume		Excellent	Good	Fair	Poor	
Alabama		X			X	X	2		X		X		X (Remix)				
Alaska		X		X					X					X			Tried one job 1½ years ago. Equipment not readily available in the area.
Arizona		X		X			1		X	X		X				X	Rejuvenating agent softened overlay above causing bleeding
Arkansas			X			X	1 - 1¼	X		X				X		X	Poor performing jobs were probably not good candidates for recycling.
California		X		X		X	¾ - 1½	X	X	X	X			X		X	Early heater-scarification project were failures and not considered cost-effective. Projects are scheduled using newer equipment.
Colorado			X	X	X		1½ - 2	X	X	X	X			X			
Connecticut		X			X		1½ - 2		X								Advantage of HIPR would be to use at night and reduce user cost.
Delaware	X																Most surfaces are open-graded and are not good candidates for HIPR.
Florida			X	X	X	X	1½	X	X			X		X			
Georgia		X				X		Developing		X							Used remix process 20 years ago with bad experience. Have spec. to allow recycling on any job.
Hawaii	X																Equipment not available in the area. Most of the construction jobs in Hawaii are too small for HIPR to be cost-effective.
Idaho		X		X		X	2	X	X								Emission controls limit HIPR use.
Illinois		X			X		1 - 1½				X	X		X	X	X	
Indiana	X																
Iowa		X		X			< 1	X			X	X				X	Problems with reflective cracking, early rutting, loss of friction.
Kansas			X	X			¾	X	X	X	X	X		X			Problems with reflective cracking after 2-3 yrs.

TABLE 1 (*Continued*)
RESULTS OF U.S. SURVEY ON HOT IN-PLACE RECYCLING

State	Extent of HIPR Use			Methods Used			Milling Depth Range, in.	Written Specs Available	Class of Highways for HIPR			Surface Seal or Overlay Common Placed Over HIPR Pavement	Performance of HIPR Pavements				Comments
	None	Experimental	≤5jobs/yr	Heater Scar.	Repave	Remix			Major	Secondary	Low Volume		Excellent	Good	Fair	Poor	
Kentucky	X																Hot mix industry is so strong, recycling seems unlikely.
Louisiana		X		X	X	X	¾-1½	X	X	X		X (for Heater Scar.)		X		X	No more heater scarification planned. Believed to not be cost effective.
Maine	X																HIPR equipment not available in the area.
Massachusetts	X																Two remixer jobs are planned for secondary roads.
Maryland			X			X	1½ - 2	X	X	X				X			
Michigan		X			X					X				X			Repaving process hardens asphalt. In the future will specify no direct flame.
Minnesota		X			X				X			X		X		X	Hot-mix industry very strong.
Mississippi		X			X	X	1½	X	X			X		X			Remix project too young to categorize performance.
Missouri	X																
Montana		X			X		1 - 1¾	X	X	X	X	X (Interstate)			X		Cost was high due to mobilization.
Nebraska	X																
Nevada		X			X		1¼					X		X			Tried to do a remix job but emissions too high. Would like to try again would like to be able to recycle at least 2 inches.
New Hampshire		X			X				X			X		X			HIPR hasn't been used since 1972.
New Jersey	X																
New Mexico	X																Considered HIPR once but would have required placing in two lifts. For 2-inch thick pavements, cheaper to do central plant.
New York			X			X	1 - 1½	X	X					X			
N. Carolina	X																Would like to know more about cost-effectiveness of HIPR.
N. Dakota	X																No contractors in the area.

TABLE 1 (*Continued*)
RESULTS OF U.S. SURVEY ON HOT IN-PLACE RECYCLING

State	Extent of HIPR Use			Methods Used			Milling Depth Range, in.	Written Specs Available	Class of Highways for HIPR			Surface Seal or Overlay Common Placed Over HIPR Pavement	Performance of HIPR Pavements				Comments
	None	Experimental	≤5jobs/yr	Heater Scar.	Repave	Remix			Major	Secondary	Low Volume		Excellent	Good	Fair	Poor	
Ohio			X	X		X	1½	X	X (Remix)	X (Heater Scar.)		X (with Heat Scar.)		X (Heater Scar.)			Heater scarification is good if pavement structurally sound. Remixing will improve both structural and AC properties.
Oklahoma		X			X		1	X	X			X					
Oregon	X							X									Two repaving projects scheduled.
Pennsylvania		X				X			X	X					X		Performance may have been better if design were of a finer gradation and if a rejuvenator had been used.
Rhode Island	X																Would like to try HIPR but haven't had the opportunity.
S. Carolina		X				X	1		X				X				Only tried one HIPR job.
S. Dakota	X																Would like to try HIPR soon.
Tennessee		X			X	X			X	X		X		X			Roads recycled using Repave process were very rough.
Texas			X	X	X	X	1 - 1½	X	X	X				X			
Utah			X		X		1	X	X	X		X		X			
Vermont		X				X			X			X				X	One remixing job was done and with a standard overlay control. HIPR will have to provide 16% longer maintenance free life to be as cost effective as standard overlay.
Virginia			X	X			1½	X			X	X			X		
Washington		X		X						X				X			Pollution problems make HIPR prohibitive.
W. Virginia	X																
Wisconsin	X																
Wyoming	X																HIPR equipment not in the area.

supply a field laboratory to provide for testing of the existing asphalt-concrete pavement and the final recycled mixture. Results of tests on the existing pavement are used in making adjustments to the amount of new aggregate, new asphalt cement, and recycling agent to be added to the RAP because the mixture components may vary with distance down the roadway. Common specification tests, such as binder consistency, aggregate grading, density, and stability, are routinely performed on the recycled mixture to verify that it meets specifications.

Comments on Performance of HIPR Pavements

Performance of HIPR pavements is generally good, according to reports by most of the states where it has been used (Table 1). It should be kept in mind, however, that many of these jobs, particularly those using modern equipment, are relatively recent. In some states, both good- and poor-performing pavements have been built. On those projects where performance was poor, it was sometimes attributed to the fact that the pavement may not have been a good candidate for HIPR.

One state reported three observed performance problems:

1. The surface oxidizes earlier than a new asphalt pavement.
2. Raveling is more probable than with a new pavement.
3. Raveling appears very early at startup sites, possibly a result of overheating or not enough virgin material introduced.

Because of the limited experience, none of the states had developed life-cycle cost information on HIPR, although opinions seemed generally favorable to HIPR when compared with conventional pavement rehabilitation and other recycling methods.

CHAPTER FOUR

MIXTURE DESIGN FOR HIPR PROCESSES

The overall philosophy of a recycled asphalt mixture design procedure is to produce a paving mixture with properties as nearly as possible like new hot-mix asphalt. Standard sampling and testing methods should be followed whenever practical. Mixture design procedures devised specifically for HIPR have not been established. Since the components and basic elements of the process for HIPR are similar to those involved in central plant hot recycling, it should be possible to use the mixture design procedure presented in NCHRP Report 224, *Guidelines for Recycling Pavement Materials* (*43*) for HIPR mixtures. The NCHRP procedure is outlined in Figure 12. Emery (*38*) developed a list to aid the engineer in considering the important items involved in recycled asphalt mixture design (Table 2).

When HIPR is used to produce a substantial pavement layer, e.g., greater than 38 mm (1.5 in.), a comprehensive mixture design procedure such as that proposed in NCHRP Report 338 *Asphalt Aggregate Mixture Analysis System or AAMAS* (*44*) may be desirable. The AAMAS system was developed to measure engineering properties of mixtures and then to judge the potential of these mixtures to function in pavement layers based on the best available and most appropriate failure criteria for each test mode. Figure 13 is a flow chart that conceptualizes the different steps in the AAMAS procedure. Four distress mechanisms were selected for incorporation into AAMAS: rutting, fatigue cracking, low-temperature cracking, and moisture damage. Secondary consideration was given to disintegration caused by raveling and loss of skid resistance. Five tests were selected as tools for mixture evaluation in AAMAS because they measure the mixture properties required by the structural models: diametral resilient modulus test, indirect tensile strength test, gyratory shear strength test, and indirect tensile and uniaxial compression creep test. Figure 14 summarizes the mixture design procedure, and Figure 15 summarizes the general AAMAS mixture evaluation procedure, identifying the four sections of the AAMAS analysis.

Another sophisticated mixture design procedure which may be desirable for use on thick HIPR pavements is the Strategic Highway Research Program (SHRP) Superpave. A general flow chart of the design procedure is presented in Figure 16. Aggregates and asphalt binder are selected using criteria specific to conditions that the mixture will face in service. A compatibility test is used to screen the asphalt-aggregate mixture for sensitivity to moisture damage (stripping). In the volumetric design portion of Figure 16, aggregates and asphalt binders are evaluated to select a gradation and asphalt-binder content that provide volumetric parameters, air voids, and voids in the mineral aggregate that meet specified criteria or guidelines. Depending on traffic level or environmental conditions, the mixture design may be complete after the volumetric design. If required, mechanical properties of the selected mixture are evaluated and performance predictions regarding low temperature cracking, fatigue, and permanent deformation are checked against criteria. After all criteria have been met, a mixture design is selected for construction. During construction, at the asphalt plant, field control tests are used to verify that the mixture is being produced in accordance with the laboratory design. Field control tests can be used as part of a quality control or quality assurance system.

Additional mixture design information is presented in the Asphalt Institute Manual Series 20, "Asphalt Hot Mix Recycling" (*45*) and in other references (*46–48*). There is no reason that HIPR mixture design should be substantially different from the design of other recycled asphalt mixture methods. Compaction procedures for pavement samples as well as mixing and compaction temperatures should simulate field conditions.

Mixture design for HIPR should consist of the following general steps: (1) evaluation of salvaged materials, (2) selection of type and amount of rejuvenator, (3) determination of the need for additional aggregates and/or asphalt, (4) preparation and testing of paving mixtures, and (5) selection of optimum combination of new aggregates, asphalt, and rejuvenator.

FIELD SAMPLING

Representative field samples should be randomly obtained from the depth of the pavement to be recycled. A visual evaluation of the pavement surface and the pavement sample should be made together with a review of construction, performance, and maintenance records to determine significant differences in the material within the area to be recycled. Roadway sections with significant differences in materials should not be combined because uniformity and predictability of results will be impaired (*43*). If materials in the roadway to be recycled vary significantly, separate mixture designs will be necessary.

Sampling locations within a project can be determined on a random basis using the in-place procedure outlined in ASTM D 3665, "Standard Practice for Random Sampling of Construction Materials." Some engineers mistakenly use random sampling only in the longitudinal direction. They will specifically direct that some samples be taken in the wheel path and some outside the wheel path depending on the prevalent pavement forms of distress.

If the pavement is exhibiting distress, visual evaluation of the pavement, laboratory testing, and review of construction records should be used to determine the source of the distress. If deficiencies of the mixture to be recycled are found to be the source of the problem, these deficiencies should be corrected during recycling or they will most likely manifest themselves soon after rehabilitation.

BINDER PROPERTIES

Asphalt content and binder properties such as penetration and viscosity are typically obtained from extracted [ASTM D 2172 (*49*)] and recovered [ASTM D 1856 (*50*) or proposed ASTM

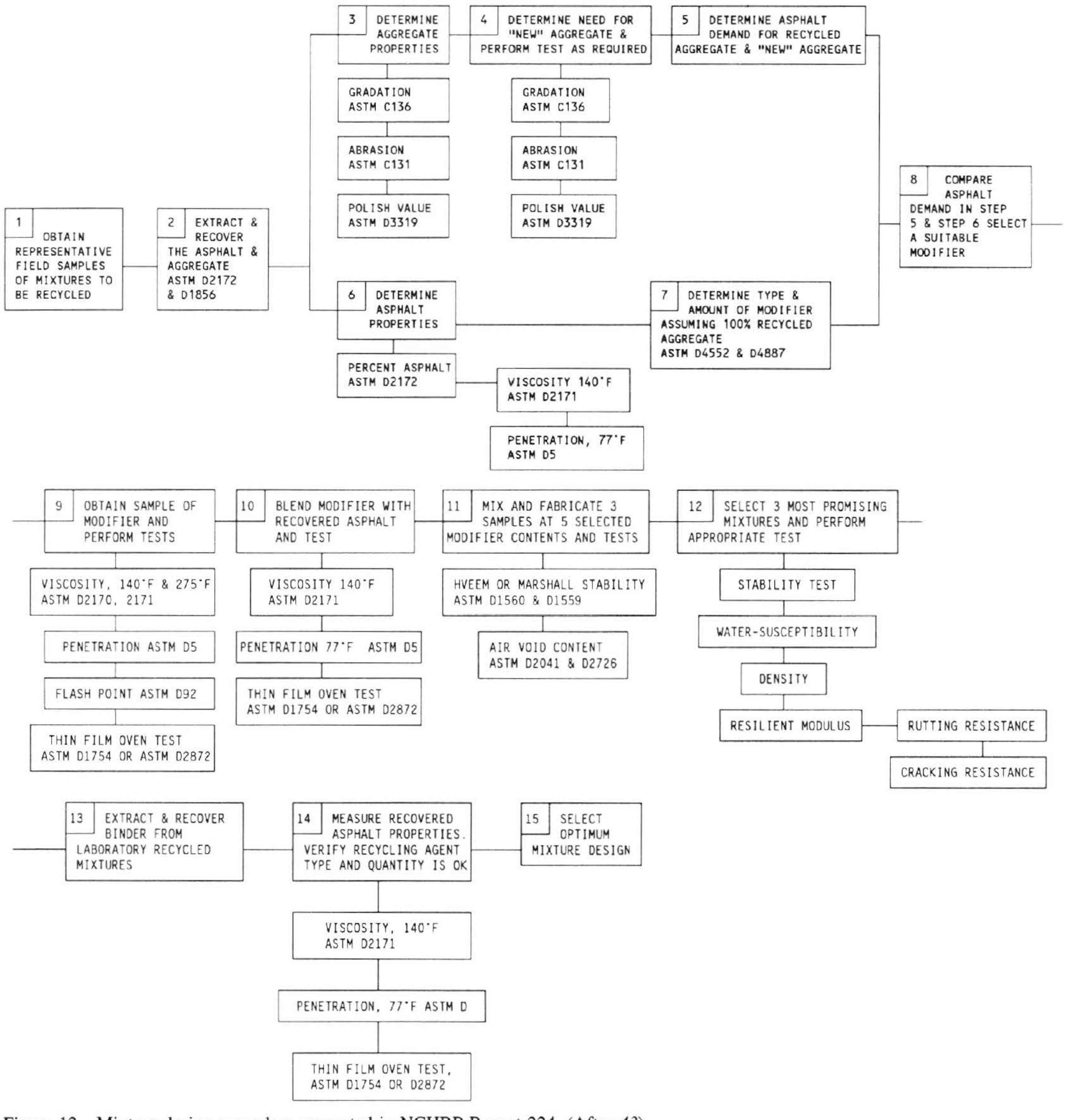

Figure 12 Mixture design procedure presented in NCHRP Report 224. (After *43*)

rotavapor method (*51*)] material. Results of these tests help estimate the type and quantity of recycling agent needed as well as the uniformity of the pavement to be recycled. ASTM D 4552 provides a standard practice for classifying hot-mix recycling agents.

The quantity of recycling agent may be optimized using ASTM test method D 4887, "Preparation of Viscosity Blends for Hot Recycled Bituminous Materials." The percentage of a recycling agent or paving-grade asphalt required to meet a target viscosity is initially determined on the basis of weight by using a viscosity

TABLE 2
RECYCLED HOT MIXTURE DESIGN PROCEDURE (After *9*)

A. DETERMINE MATERIAL PROPERTIES AND PROPORTIONS

1. Obtain representative samples of RAP,[b] new aggregates,[b] and new asphalt cement selected.[c]
2. Determine asphalt cement content of RAP (including penetration/viscosity extraction and recovery).[c]
3. Determine gradation of RAP aggregate, including bulk relative density.
4. Determine gradation, percent crushed, bulk relative density, and absorption of new aggregates.[d]
5. Determine if adjustments in aggregate gradation are necessary to develop voids in mineral aggregate (VMA) and select as necessary, ensuring adequate stability is maintained.[e]
6. Determine the total aggregate grading, check specification compliance and modify as necessary.

B. PREPARE MATERIALS FOR MIXTURE DESIGN

1. Determine increments (range) of total asphalt-cement content required to develop specified parameter plots.
2. Select recommended grade or preferred penetration/viscosity of new (additional) binder.[c]
3. Determine mass of RAP, new aggregates, and new binder for each increment.

C. COMPLETE MIXTURE DESIGN

1. Prepare compacted briquettes incorporating RAP,[f] new aggregates, and new binder.
2. Test briquettes - bulk relative density, maximum relative density, stability, flow, air voids, VMA, and appearance.
3. Report recommended recycled mixture design.

D. QUALITY CONTROL/QUALITY ASSURANCE (QC/QA)

1. Similar to conventional hot mixture with addition of monitoring RAP (moisture content, gradation, and asphalt-cement content) and *more* emphasis on absolute viscosity and penetration of recovered binder.

[a] Adapted from current Ontario Ministry of Transportation procedures that incorporate the Asphalt Institute Marshall method of hot mixture design.
[b] All samples must be representative. Process control data should be used.
[c] The new asphalt cement selected must provide properties in the recycled mixture meeting specifications.
[d] For new aggregates that have not been used before, factors such as petrography and stripping resistance must be considered. This also applies to RAP aggregate, if aggregate-related pavement distress is involved.
[e] In order to develop VMA, it is often necessary to incorporate a clean, fine aggregate.
[f] The RAP must be carefully dried during testing to avoid excessive asphalt-cement hardening, and then combined with suitably heated new aggregates to give an overall mixing temperature meeting the appropriate combined RAP asphalt-cement and new asphalt-cement mixing temperature viscosity.

blend chart as illustrated in Figure 17. A 10.0±0.1-gm (minimum) trial blend consisting of the recycling agent or paving grade asphalt and reclaimed RAP binder is prepared in the laboratory. The viscosity of the trial blend at 60°C (140°F) is compared with the target viscosity. If the blend viscosity is not within the limits of Specification D 3381 about the target value, another trial blend is prepared using adjusted proportions of the same or an alternate grade modifier, or both, and the RAP binder. A batch blend larger than the trial blend can be prepared after the target viscosity is achieved, to facilitate additional tests.

It should be pointed out that viscosity and penetration of recovered asphalts normally provide reasonably good estimates of the properties of the binder in the pavement; however, there is considerable opportunity for error in the recovery procedures. Nevertheless, it is normally desirable to select the type and quantity of rejuvenator that will restore the binder as closely as possible to its as-placed rheological properties, unless, of course, the original properties are the source of poor performance. Field experience shows that laboratory tests often indicate more recycling agent than is needed in practice; therefore, adjustments may be required during field operations.

Epps et al. (*43*) indicated that because some recycling agents

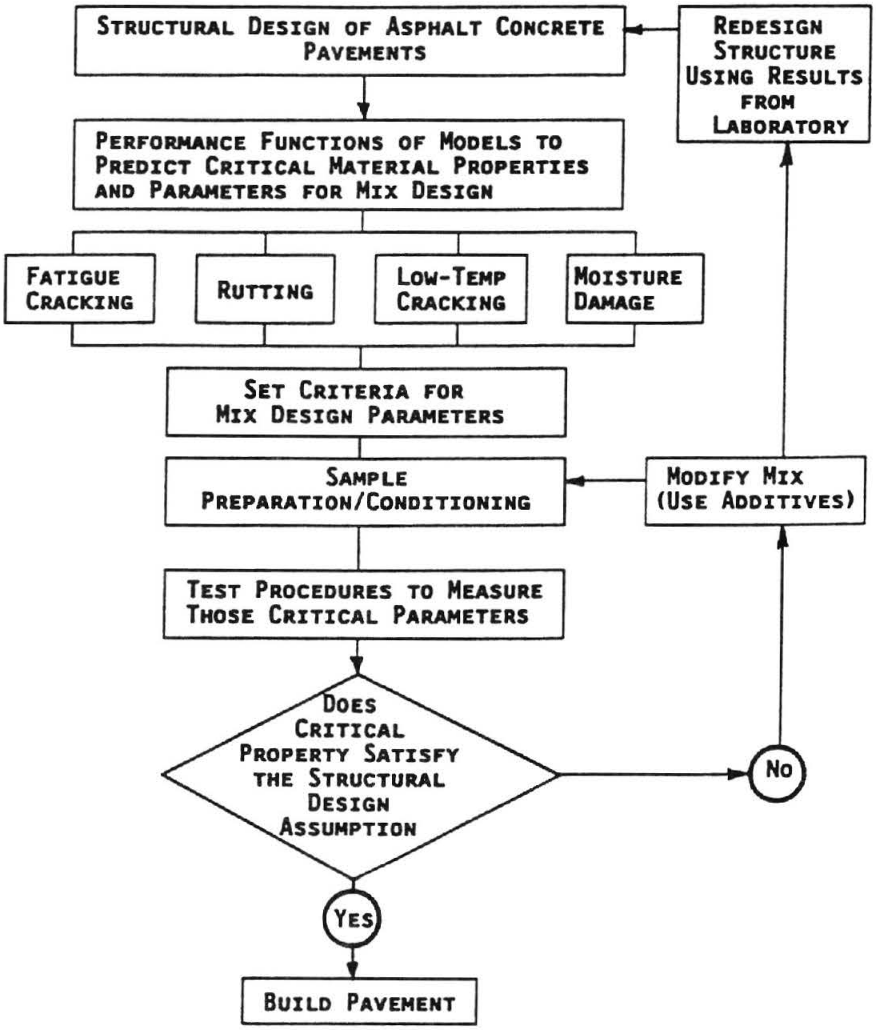

Figure 13 Conceptual flow chart illustrating the AAMAS procedure. (After *44*)

may not be compatible with the salvaged asphalt, a thin-film oven test should be performed on the recovered asphalt-rejuvenator blend selected. They stated that a ratio of the aged viscosity to original viscosity of less than 3 indicates that the recycling agent is likely compatible with the recovered asphalt.

AGGREGATE PROPERTIES

Large cores or masses of materials should be obtained and heated prior to crushing to simulate the hot milling or scarification process. Large cores minimize the number of cut aggregate per unit weight of sample. These samples should be heated in a 275°F (approximate) oven for 20 to 30 min (depending on the age of the sample) to facilitate crushing by hand. Mechanical crushing may significantly alter the aggregate gradation. Hot milling reportedly has little effect on aggregate gradation, neither should laboratory crushing of samples used in mixture design.

Aggregates recovered from the samples should be tested to examine uniformity within the project and ensure they meet agency specifications. Important properties include gradation, durability, and skid resistance (if used as a surface course). If the mixture requires new aggregate to meet specifications, the remixing process may be the only viable HIPR option.

MIXTURE PROPERTIES

Ideally, about five different blends of recycled and virgin materials should be fabricated, tested, and compared with agency requirements (*43*). These preliminary tests should vary the type and quantity of virgin materials. Standard mixing and molding procedures should be used.

Laboratory-prepared samples should be allowed to cure for a sufficient time at an appropriate temperature to permit the recycling agent to diffuse throughout the old asphalt and/or absorb into the aggregate prior to testing. Testing too soon might give properties uncharacteristic of the cured field mixture. Appropriate cure times and procedures for hot recycled mixtures have not been established. An oven curing procedure after mixing and before compaction has been reported by Sousa et al. (*52*) for virgin mixtures. The procedure involves holding the mixture at 60°C (140°F) for 15 hours prior to compacting. Compaction is performed at

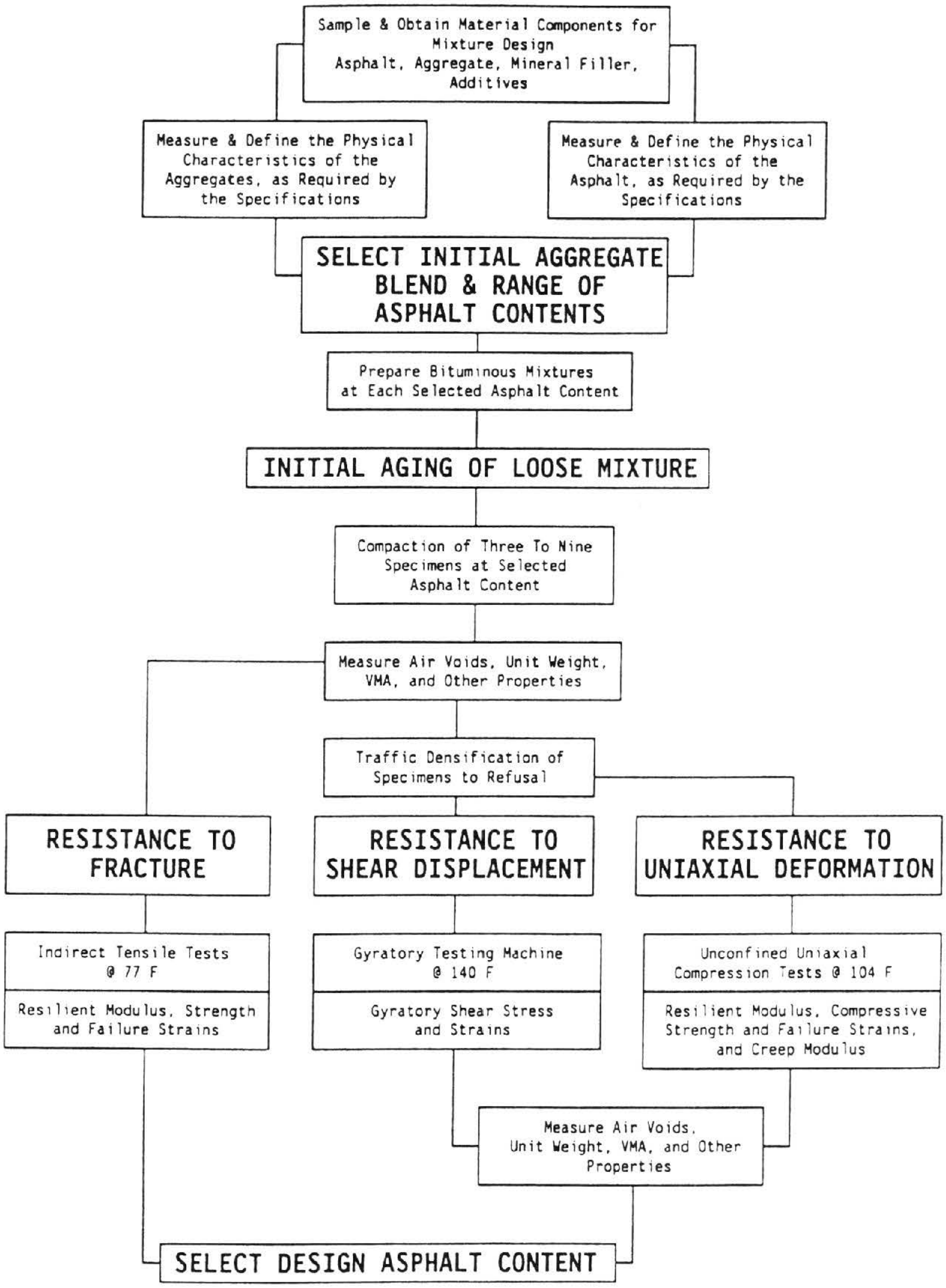

Figure 14 Flow chart for the design of dense-graded asphalt concrete mixtures. (*44*)

115°C to 135°C (240°F to 275°F). This curing method may be useful until a method is developed specifically for hot-recycled mixtures. Laboratory conditions should model field conditions as closely as possible. Therefore, curing laboratory-compacted specimens prior to testing may be a more realistic scenario than that described above.

The most promising mixtures produced should be evaluated in detail to determine properties that can be used in pavement thickness design and for durability considerations such as water susceptibility. The amount of testing will depend on the capability of the agency (*43*) and the size of the project. The mixture with optimum properties and acceptable economics should be selected.

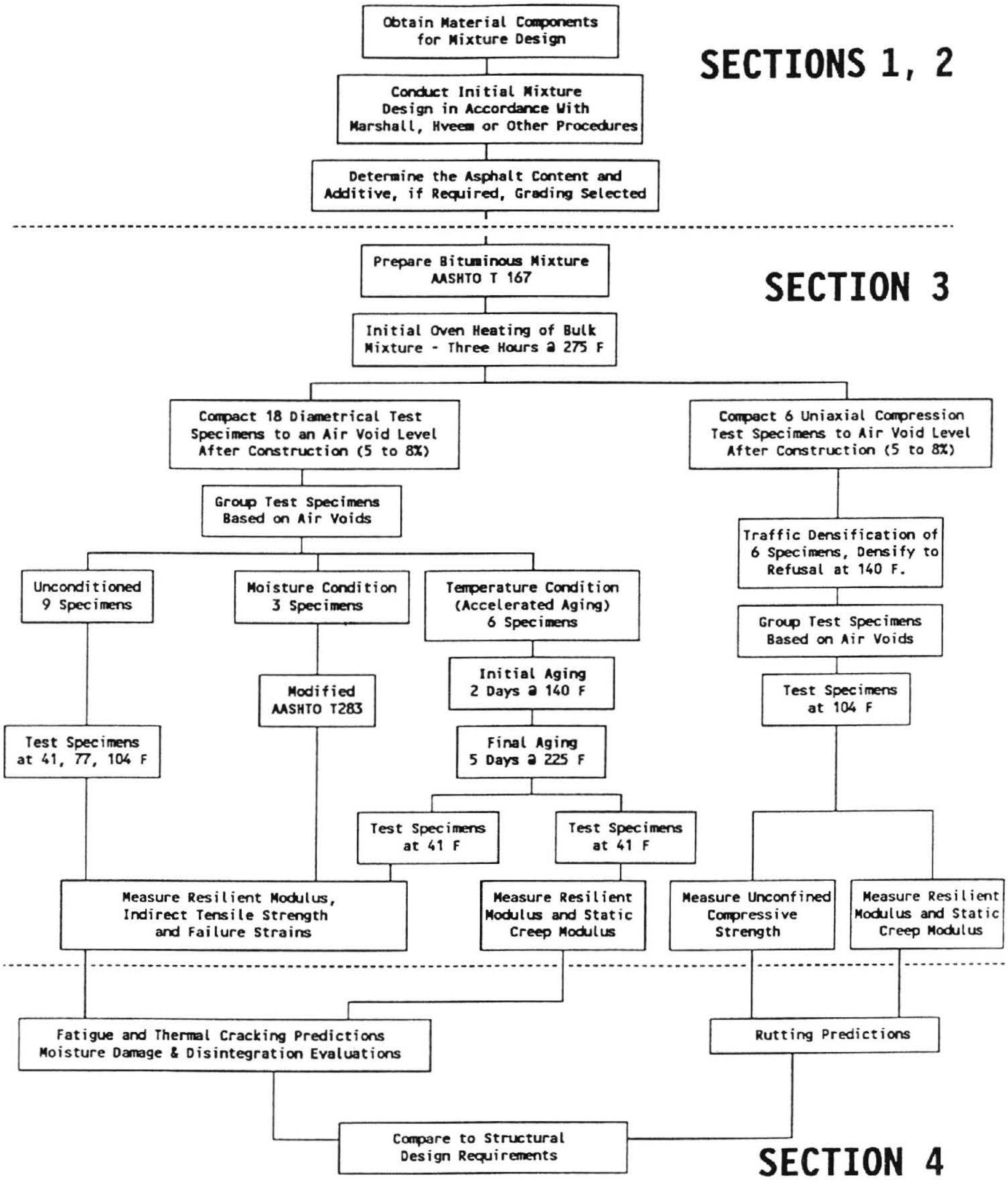

Figure 15 Flow chart for the AAMAS mixture evaluation procedure. (After *44*)

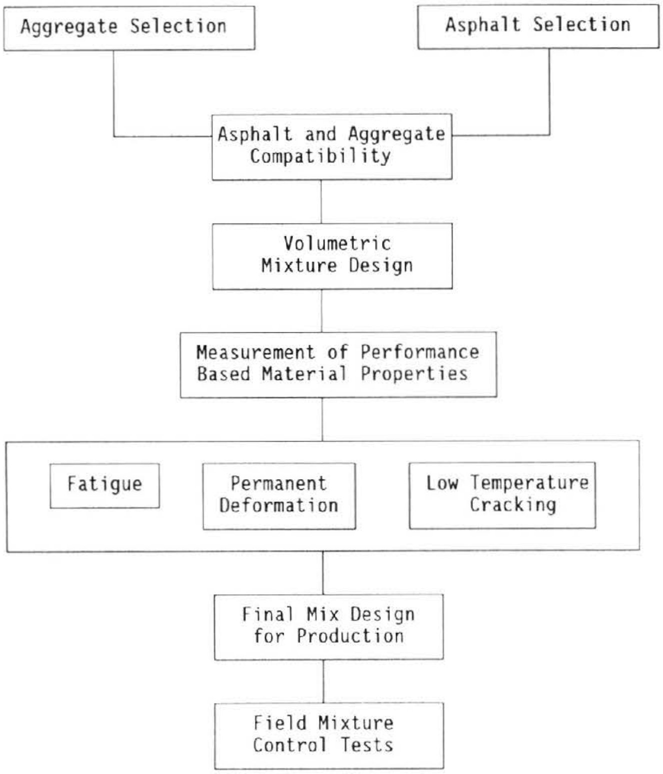

Figure 16 Superpave Mixture design procedure.

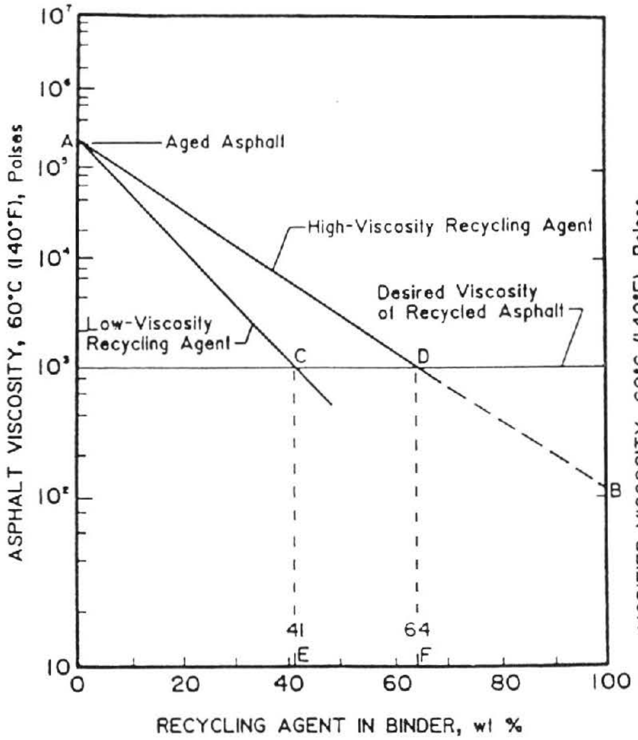

Figure 17 Method for determining optimum amount of rejuvenating agent in recycled asphalt (ASTM D 4887).

CHAPTER FIVE

HIPR CASE HISTORIES

Because the experience of others is always valuable when considering the application of a previously untried process, case histories from several HIPR projects are summarized in Table 3. Although most published reports emanate from work on major highway and airport pavements, much HIPR is conducted on municipal streets and roads.

A review of published case studies shows that HIPR often presents an attractive alternative to conventional pavement leveling and resurfacing processes. When executed properly, HIPR can create a pavement no different in appearance or ride from a pavement that has been resurfaced by conventional methods. The process provides a recycled pavement that has improved mixture properties and cross slope. By heating the adjacent pavement, it yields excellent bonding at the interface between the old pavement and the new overlay and at the construction joint between the HIPR pavement and the adjacent lane. It has been used successfully on city streets and highway and airport pavements that possessed adequate structural integrity. The single-pass operation is convenient to the motoring public and the agencies involved in the coordination of road surfacing, requiring less time as well as fewer haul trucks—and thus drastically reduced congestion—than conventional paving operations. HIPR allows pavement maintenance funds to go further while contributing to the conservation of raw materials and energy and reducing landfill requirements.

Specific lessons learned from selected case histories are itemized below:

- A thorough and comprehensive preliminary investigation and testing program should be given a very high priority (*60*).
- Careful consideration must be given to preparing specifications that are relevant to the intended construction program, and the specifications must clearly describe the type of equipment that will provide an acceptable finished product (*60*).
- One agency indicated that for all in-place recycling projects, greater than normal resources are required for both inspection and materials testing (*41*). This is partly because the process is relatively new and also because it offers more opportunities for variability than conventional paving processes (*62*). HIPR equipment is inherently complex and is constructed in such a way that many of the operations cannot be readily observed. Inspectors should be trained to analyze the consequences of various mechanical failures and operational malfunctions (*58*). Items specifically associated with HIPR might include the consistency of the pavement being recycled (ensure proper mixture design), preheating operations (avoid charring asphalt), the recycling depth, and sampling and testing to ensure proper rejuvenation and no overheating.
- Heating and mixing of existing pavement during HIPR significantly increases the viscosity of the asphalt cement. Guidelines to account for asphalt hardening directly attributable to the HIPR process should be developed (*60*).
- Excess asphalt mastics used for joint and crack filling operations create flare-ups under the preheater. A conventional garden fertilizer spreader used to distribute a strip of hydrated lime 1 mm to 2 mm thick along the heavily filled cracks reduced the flare-ups; sand may also be considered (*60*). In some cases, the crack sealant material is removed prior to recycling (*41*).
- Isolated areas of an existing pavement with excessive asphalt content can be detected by bleeding following the preheaters. In these areas, the recycling agent application rate can be reduced manually, if deemed necessary, to avoid subsequent flushing under traffic.
- In cool northern climates or in winter, night work has sometimes been impractical because of low ambient and pavement temperatures (*41*).
- In some cases, it has been possible to achieve adequate compaction at mat temperatures more than 20°C (36°F) below those normally desired. One explanation: the viscosity of the "effective" binder is actually close to the desired value. That is, in the brief interval of time between mixing and compaction, the recycling agent may have an opportunity to diffuse only into the effective asphalt cement (the film surrounding the aggregate or clump of aggregates), not into the pores of the aggregate where the rest of the aged asphalt esixts (*41*).
- There can be considerable gaseous emissions (blue smoke) at times from heating and mixing equipment. Emissions can be especially high on pavements with excessive joint or crack sealer at the surface. Newer equipment has significantly reduced or eliminated this problem (*4*). Assessments of this impact on the environment should consider the fact that HIPR eliminates disposal of waste material.
- Attempts to push the heat deeper into the pavement result in excessive heat at the surface if either a greater exposure time or a higher source temperature is used (*11*). Excessive heat and exposure time is a concern when considering the durability of the recycled mixture (*63*).
- Conventional gradation specifications, design properties, and compaction requirements should be used when specifying HIPR or permitting it as an alternative.
- Strength equivalencies used in the pavement design process should be the same as those normally assigned to a similar standard mixture produced by conventional processes (*64*).
- Recovery of asphalt cement from recycled mixture should be made at regular intervals during the production process. Viscosity should be in a range comparable to that obtained from conventional asphalts (*64*).
- The maximum scarification depth for most successful HIPR operations is 50 mm (2 in.); however, 75-mm (3-in.) depths have been achieved using tandem scarifiers and/or rotary milling.
- The mean viscosity of the recovered binder from recycled mixtures can be closely controlled. However, considerable variation in viscosity throughout the job may result. Sometimes it is difficult to add enough rejuvenator without overasphalting the mixture (*19,61*).

TABLE 3
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Heater Scarification Process									
City of Richmond, Virginia 1988 (4)	Unknown	Various city streets	Fatigue cracking with some rutting	Natural, heater-scarify and 25 mm overlay later	25mm/0	Reclamite at 0.45 l/m^2	Unknown	Steel wheels at rear of heating units. No mix testing prior to HIPR.	Some raveling of recycled layer prior to overlaying.
City of Grand Prairie, TX 1988 (4)	Unknown	Two-lane residential street with curb and gutter	Few transverse and longitudinal cracks	Dustrol, heater-scarify and overlay later	25mm/0	Reclamite at 0.45 l/m^2	Unknown	Steel wheel at rear of heating units. Manually controlled screed.	Not available.
Louisiana DOT 1977 (53)	Unknown	14.2 km of U.S. 61	Rutting up to 38 mm deep	Benedetti heater-scarify and overlay later	19mm/0	Reclamite at 0.45 l/m^2	350°F	Scarification depth insufficient due to prolonged rainfall.	Extensive raveling prior to overlaying. Finished surface had open appearance. Did not eliminate all rutting. Skid numbers of recycled surface unacceptable.
Repaving Process									
FAA, Carrabelle, Florida 1990 (54)	$4.28/m^2	Thompson Field Airport. 30 m x 1212m runway	Unknown	Repaver	25mm/25mm	Unknown	Unknown	Considered most environmentally acceptable option. Required 6 days.	Officials pleased that job met specs and appeared cost effective and had short down time.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Florida DOT 1979 (55)	$\$2.99/m^2$. A savings of 25% estimated	US 41, Ft. Myers, Fla. 3.9 km, 6-lane. ADT-39,000	Rutting, cracking, low friction. Pavement structure was OK.	Cutler Repaver	25mm/19mm	EA-SS-1, 0.27 l/m^2	175°F to 250°F	An FHWA demonstration project. Saved substantial energy.	PSI** increased from 3.53 to 3.89. After 14 yrs pavement has 12mm ruts, hairline cracking, and fair ride quality. Overall performance good.
Louisiana DOT 1980 (56)	Unknown	Metairie Rd from US61-IH-10 5.8 km curb and gutter section	Cracking, rutting	Cutler Repaver	25mm/20mm	CSS-1, 0.45 l/m^2	Unknown	Numerous locations with open texture. No transverse distribution of scarified material.	Eliminated cracks, and restored cross slope, and minor improvement of longitudinal undulations. Began raveling in 6 mo. Generally, satisfactory after 5 yrs.
Louisiana DOT 1986 (57)	$\$4.90/m^2$ as compared to $\$7.40/m^2$ for conventional	11.4 km of US 71	Overlay on PCCP*** had reflection cracks with severe spalling which gave poor ride quality.	Cutler Repaver	25mm/38mm	ARA-1 0.63 l/m^2	Mat 150-265°F with 215°F avg. behind paver	Production 0.8-2.6 mi/day. Most samples disintegrated during coring. New mix lost 20-40°F between haul truck and final screed.	Difficult to achieve density. Low mat temp. Recycled section performing about equivalent to control section.
City of Phoenix 1990 (42)	$\$3.59/m^2$	City collector street. 10,000 yd^2	Severe alligator cracking with longitudinal cracking distortions, bleeding and raveling	Cutler Repaver	19mm/25mm	Yes, Type and quantity Unknown	Unknown	Heated, stripped, and windrowed existing chip seal then heated remaining surface course.	Early performance good. Low pollution favorable to city officials.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Lee County, Iowa 1990 (17)	$3.41/m^2$	Rural roads X-38 and X-48	Oxidized surface, cracking, 13 mm ruts	Cutler Repaver	19mm/25mm	Elf ETR-1 at 0.36 l/m^2	105°C	Rejuvenator application rate geared to forward speed of machine.	Early performance good. Officials pleased with relatively little traffic disruption.
FAA Texarkana, Texas 1986 (36)	50 percent savings reported	Airport- 2011 m and 25 yr old	Aged, brittle mix. Low friction.	Cutler Repaver	25mm/25mm	Type unknown 0.54 l/m^2	230°F	Mix disintegrated when cold milling was attempted; could not control depth.	After 6 yrs a few surface cracks have appeared in isolated places. Otherwise, performance is excellent.
Connecticut DOT 1981 (58, 59)	$4.33/m^2$. 16% more than control	Rt. 15 at Westport, Connecticut 4.7 km, 4-lane divided	Rutting. Otherwise fairly good condition.	Cutler Repaver	25mm/25mm	AE-300R, 0.36 l/m^2	250°F ± 30°F by spec.	AE-300R was unsuitable for this job; too low in maltenes. Average scarified depth was < 13mm.	Some reflection cracking. HIPR same as control. Recycling cost about 16% more than conventional.
Remixing Process									
Transport Canada* 1988 (60)	Unknown	Prince George Airport, British Columbia	Extensive longitudinal, transverse, and random cracking with raveling. Annual crack sealing no longer cost effective.	Taisei Rotec Remixer	50 mm/50mm -- No new aggregate added to RAP.	Cyclogen-L at 0.36 l/m^2 Varied based on observed flushing during heating	110°C-150°C was specified. Maintained at low end.	Thin layer (1-2mm) of hydrated lime was applied to excess mastic at filled cracks to prevent flare-ups during preheating.	Extraction tests verified excellent control of rejuvenator application rate. Asphaltenes decreased by 24%; polar compounds increased 143%, which indicates improved durability.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Defence Construction Canada* 1989 (41)	\$3.58/m^2 for the 40 mm/19mm -- \$4.17/m^2 for conv. 50 mm overlay	Airfield pavements at Canadian Forces Base, Edmonton, Alberta, 330,000 m^2	Severe raveling and thermal cracking. Badly weathered, oxidized appearance	Artec Remixer -- Only a small area was remixed	40 mm/50 mm overlaid later; or 40 mm/19 mm repave	RJO #3 at 0.4 l/m^2	120°C behind paver was targeted value	Specifications had stringent requriements for rideability and surface permeability. Removed striping and crack filler before recycling.	Equipment was capable of heater-scarification, repaving, and remixing. Early performance of pavement has been good. Author states that pavement flushing is a concern, and that more inspection and testing will be required for all HIPR.
Texas DOT 1991 (37)	\$2.15/m^2 for recycling portion only	IH-10 and SH-87 near Beaumont	Severe rutting, age-hardened mix. Raising elevation by overlaying was impractical	Wirtgen Remixer	25mm to 31mm	ARA-1	About 240°F	High traffic limited production to 1400 m/day.	No drop off during construction enhances safety. Early performance satisfactory.
Tennessee DOT 1990	Unknown	Northern-most 9.7 km of IH-75 in Tennessee	Severe rutting and other forms of distress.	Wirtgen Remixer	75 mm + 24 kg/m^2 of new mix	AES-300RP (polymer) at 0.63 l/m^2	225°F	Milling to 75 mm depth slowed production to 1.1 m/min. Added extremely coarse admixture to improve stability.	Officials pleased with density, stability, asphalt content, and gradation. Overall early performance very good.
Alabama DOT 1989 (18)	Unknown	Four mile stretch of US 78 near Fruithurst	Cracking and rutting. Unsightly.	Wirtgen Remixer	38 mm + 14 kg/m^2 of new mix	Unknown	Near 300°F	First remixing project in the southeast.	Minimal traffic disruption was important. Early performance OK.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Mississippi SHD 1990 (24)	Unknown. 40% savings reported	55 lane-km of IH-59 in Lauderdale County	Highly polished with some rutting.	Wirtgen Remixer	38 mm + 15 kg/m^2 of new mix	Yes, unknown	230°F	Pavement was 18 yrs old and was structurally sound.	Early performance OK DOT pleased with project.
Texas DOT 1990 (21)	Unknown	IH-35 in La Salle County near Cotulla	Surface was severely age-hardened with cracking and rutting.	Wirtgen Remixer	50 mm + 8 kg/m^2 of new mix	None used. Asphalt was in new mix.	Unknown	Surface was cold-milled then top 50 mm of base was recycled. Used 2 preheaters.	Officials believe process is promising. Early performance OK.
Canadian Dept. of National Defense* 1989 (20)	Acceptable economic alternative	Lancaster Park Airfield near Edmonton 4250m	Unknown	Artec Repaver and Remixer	38 mm + 19 - 50 mm overlay; 38 mm + 41 kg/m^2 new mix	Shell RJO-3 at 0.19 l/m^2	Unknown	Agency required close adherence to specifications.	Specs on density, temperature, penetration, scar, depth and smoothness of surface were met. An acceptable economic alternative.
British Columbia Ministry of Highways* 1989 (20)	\$1.70/m^2 for recycling only	Trans-Canada Highway (Rt 1) near Vancouver, 126 lane-km	Rutting, surface cracking and other age-related distress	Artec and Taisei Remixers	38 mm to 63 mm (no new material added)	Unknown	105°C minimum	Used a 2-stage milling/heating process.	All specs were met. Ministry was satisfied with final results. Appears to be an acceptable economic alternative. Reduced traffic disruption.
Texas DOT 1989 (26)	\$2.57/m^2 including 30 kg/m^2 of new mix	IH-20 from Louisiana, border to FM450, 51 km, ADT-18,000 20% Trucks	Poor ride quality and some raveling. An other portion was overasphalted	Wirtgen Remixer	38 mm + 30 kg/m^2 new mix	ARA-1 at 0 to 0.71 l/m^2	230°F	Part of job designed to receive no rejuvenator, as it was already overasphalted.	Officials pleased with early performance. Pleased with safety aspects of process. Good ride quality.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent / Mix Temperature	Unique Features	Performance/ Remarks
Texas DOT 1987 (33)	$3.05/m^2 a savings of 34% over conventional	US 259 in Lone Star. Major arterial carrying heavy trucks	Oxidized, block cracking. One-inch ruts at intersections	Cutler Remixer	38 mm + 17 kg/m^2 new mix	AC-5 used with new mix / 200°F behind screed	Remixer had no pugmill. Curb and gutter sections.	Early performance OK. Pleased with economics.
Oregon DOT 1987 (34)	17% savings estimated	82nd Ave from N.E. Wasco to S.E. Division a 5-lane major arterial	Rutting, cracking, very poor drainage	Taisei Remixer	Up to 50 mm + various new mix	Non-emulsified product / Unknown	Train averaged > 6 m/min. Various quan. new mix added to correct drainage.	Officials very happy with project outcome. Ride quality and early performance good.
Texas DOT 1986 (35)	Unknown	US 380 from Decatur to Bridgeport. 18,400m^2. Very heavy truck traffic.	Rutting, cracking, surface irregularities	Wirtgen Remixer	50 mm + 22 kg/m^2 new mix	None / Unknown	Specially designed admix had only 3% asphalt.	HIPR equipment apparently caused 2 longitudinal cracks to appear at 3yrs. Ruts near 1/2" at 7 yrs.
South Carolina DOT 1983 (61)	Unknown	S.C. 291 from U.S. 29 to N. St. in Greenville. 1.2 km, 6-lane ADT-37,300	Unknown	Wirtgen Remixer	41 kg/m^2 surface mixed with 18 kg/m^2 virgin mat	Exxon AC-2.5 used in virgin mix / Mat behind screed 230°F	On occasion aged asphalt was heated to the fire point. Recovered asphalt viscosity was 41,000 poise.	Stability, density and workability compare well with virgin mix. Durability of mix is a concern.

TABLE 3 (*Continued*)
SUMMARY OF SELECTED CASE HISTORIES OF HOT IN-PLACE RECYCLED PAVEMENTS

Agency/ Date Recycled	Cost Information	Description of Job	Condition of Old Pavement	HIPR Equipment Used	Milling Depth/ Overlay Depth	Rejuvenating Agent	Mix Temperature	Unique Features	Performance/ Remarks
Texas DOT 1981 (35)	$\$1.59/m^2$ inch for recycling only	US 59 near Lufkin, 20,000 ADT	Severe rutting	Wirtgen Remixer	50-38 mm + 20% new mix	ARA-1 at 0.1 0.45 l/m^2	225°F	Existing mix was asphalt sensitive and overasphalted, a lean mix was used as admix.	Severe rutting reoccurred. HIPR again by same process in 1984. Rutted again. Mix was removed and replaced in 1988.
Louisiana DOT 1990 (19)	$\$4.59/m^2$ including recycling, rejuv. agent and admixture	US 90 from La 99 to Jennings	Poor ride quality due to spalling of cracks reflected from underlying PCCP***	Wirtgen Remixer	38 mm + 30 kg/m^2 new mix	ARA-1 at 0.9 l/m^2. Elf AES-300RP used in a short section	225°F - 300°F	Averaged 1.4 lane-km per day. Reduced asphalt content of admix to 4%.	Initial economic benefit realized. Early performance OK.

* Cost for jobs in Canada given in Canadian dollars.

** PSI - Present serviceability index.

*** PCCP - Portland cement concrete pavement.

• The contractor should furnish a representative responsible for observing and adjusting the infrared heaters as they pass over the existing pavement to avoid overheating and thus minimize excessive hardening of the asphalt cement (*61*).

• Typical average construction rates may range from 610 to 2,800 lane-m (2000-9200 lane-ft) per day, depending on depth of scarification, pavement materials and temperature, recycling equipment, and traffic.

• Direct flame contact with the existing pavement surface should be avoided because it has caused excessive hardening and even charring of the asphalt. Specifications should require radiant preheating or limit the surface temperature and prohibit burning or charring of the asphalt cement.

• HIPR is acceptable on roads with one seal coat; however, two or three seal coats at the surface may cause the material to smoke and even catch fire. The seal coats act as insulation that prevents heat from penetrating to the pavement below (*24*).

• The ideal candidate for HIPR is a pavement that is not excessively oxidized (*18*). The existing asphalt cement must be capable of being rejuvenated to its original, as-placed consistency.

• None of the HIPR methods currently in use are designed to provide for corrections in grade. They can smooth out some surface irregularities such as rutting or corrugations (*4*) but they cannot remove large undulations due to volume changes in the base or subgrade.

• Heater-scarification alone can provide an acceptable intermediate or leveling course but is not acceptable as a surface course. An overlay for heater-scarified pavements is normally recommended (*4*).

• Where cold milling was destroying a hard, brittle, cracked asphalt pavement down to the unstabilized base, HIPR was used successfully to recycle the top 25 mm (1 in.) and add an additional 25 mm of new surface (*36*).

CHAPTER SIX

RELATIVE PERFORMANCE OF HIPR PAVEMENTS

CORRECTION OF PAVEMENT DISTRESS

HIPR processes offer methods for in situ correction of mixture deficiencies in pavements that are not possible using conventional reconstruction techniques.

In well-designed and properly constructed HIPR pavements, performance in terms of cracking, rutting, raveling, stripping, and skid resistance should be approximately equivalent to that of a well-designed conventionally constructed pavement. There are more opportunities for error with existing HIPR pavements than with conventional paving operations. As a result, there is typically more variability within a finished pavement and between paving projects.

Only short-term performance data have been published for the modern HIPR techniques. Heater-scarification, which has been in use for many years, has demonstrated reduced reflective cracking in a subsequent overlay. The older machines often had difficulty in leveling severely rutted or rough surfaces. Ride quality specifications often had to be waived. Many of the modern HIPR processes can virtually eliminate high-frequency surface irregularities due to corrugations, shoving, and rutting in the surface mixture; however, low-frequency undulations in a pavement surface caused normally by movement in the substrate are not removed by the process. As with conventional virgin or recycled mixtures, if the source of the problem (aggregate grading or quality, binder quantity or quality, moisture susceptibility, surface texture) is not eliminated in the HIPR process, the problem will manifest itself again in the recycled mixture.

SERVICEABILITY

In the early years, performance of heater-scarified pavements varied considerably because specifications were not effectively prepared. Many projects were constructed without proper design and quality control was lacking. Yet many lane-miles of excellent work were constructed and have performed well beyond the early expectations of a stop-gap measure designed to gain 3 to 5 years of life. There are numerous projects that have served for more than 10 years (almost equivalent to the normal life expectancy of a 50-mm overlay) (*7*).

Service lives of 8 to 12 years for pavements produced by the repaving process have been reported. Shoenberger et al. (*4*) conclude the repave procedure should provide a surface course equal to that produced by conventional overlays. They also conclude that the process will probably be cost effective only in limited circumstances, such as locations where it is used in conjunction with other procedures. Placement of an overlay by a conventional paver may be more economical than passing a virgin mixture through a recycling train for placement over the recycled asphalt concrete.

Shoenberger et al. (*4*) further conclude that the advantage promoted by equipment manufacturers, that of providing a greater bond between the surface course and the underlying pavement, is not considered a significant benefit for most paving applications. However, work by Ameri-Gaznon et al. (*65*) demonstrates that the degree of bond has a substantial influence on rutting potential in surface layers, particularly under high tire pressures where braking and cornering action is common. Their work demonstrates that the ratio of induced shear stress within the pavement surface to shear strength of the surface layer under the stress state actually induced may drop drastically as bonding is reduced (even slightly, say 10 percent).

In one case, the initial pavement serviceability index (PSI) for a surface produced by the repaving process was reported to be about 0.5 less than that of a conventionally resurfaced pavement (*55*). Others have reported good to excellent serviceability (*57*).

Since the remixing process is only about 9 years old, the serviceability of remixed pavements has not been established. Based on early performance, it is anticipated that the service life of remixed pavements will be about the same as conventional pavements (*66*). Shoenberger et al. (*4*) point out that caution should be applied when using the remixing processes to obtain a wearing surface. The quality and durability of this surface mixture compared with a virgin mixture are not well documented. Available information indicates that there is a built-in variation in the mixture being placed, since additional amounts of new mixture incorporated are based on averages, with the exact amount varying with surface smoothness. They further state that quality control procedures for the remixing process should be improved before it is considered for use as a high-quality pavement. This is of particular importance when a new mixture is being added to correct a problem in mixture component proportions. The proportions of the mixture must be consistent and meet specified requirements verified by testing on a prearranged schedule.

STRUCTURAL VALUE

Most of those who have reported a structural value or layer coefficient for HIPR mixtures have given them the same value as conventional hot-mix asphalt concrete (*67*).

During the phone survey of the 50 state DOTs, only 17 said they had considered a structural value for HIPR pavements. Fourteen of these stated they considered the structural value of an HIPR pavement layer about the same as that of virgin hot-mix asphalt. Three indicated they assigned it a structural value of slightly less than virgin hot-mix asphalt.

COMPARATIVE COST

Because of wide differences in processes, equipment, and reasons for choosing a particular rehabilitation process, direct comparisons between different HIPR processes or between HIPR and conventional methods are difficult and are project dependent. Actual costs and cost savings realized will, of course, depend on many local factors. Total cost will vary depending upon rejuvenator requirements, additives and admixtures used, local material and fuel costs, and location.

In 1990, it was reported that the cost of heater-scarification to a depth of 25 mm (1 in.) and incorporation of a recycling agent is approximately \$1.20/m^2 (\$1.00/yd^2) (*4*). An additional 25-mm (1-in.) overlay costs approximately \$1.97/m^2 (\$1.65/yd^2). Therefore, to recycle and overlay a pavement in this manner using the two-pass method would cost approximately \$3.17/m^2 (\$2.65/yd^2).

Based on published figures (*17,3,42,56,57,59*), the cost of recycling the top 25 mm (1 in.) of a pavement surface and simultaneously placing an additional 25-mm (one-in.) overlay using the repaving process varies around \$3.50/m^2 (\$2.93/yd^2). Cost savings up to 25 percent are reported over cold milling and overlaying using conventional procedures.

When the remixing process is compared with cold milling and applying a new overlay, cost savings of 5 percent to 50 percent are reported (*19,20,33–35,37,68,69*). A reasonable estimate for remixing when a 25-mm (1-in.) cut is made and 10 to 20 percent virgin material is added is approximately \$2.15/m^2 (\$1.80/yd^2).

Cost alone does not tell the whole story. HIPR offers options not available from conventional paving techniques, such as rejuvenating a pavement or correcting a mixture deficiency in an existing pavement, as well as conserving materials and energy. A conventional overlay may require covering shoulders to maintain profile, whereas HIPR would not raise the travel lane enough to require adjustments in shoulder height. HIPR can be specified to address specific problems or may be included as an alternative to conventional bid items (such as cold milling plus plant recycling). Because of the limited number of contractors in the HIPR business, such alternate bidding may be beneficial in order to obtain competitive bids.

ENERGY SAVINGS

In view of the growing energy problem, energy demands as well as economics should be considered in developing paving strategies. In the future, it may become increasingly important to select modes of construction that minimize energy consumption without sacrificing quality.

In 1981, Servas (*70*) concluded that, although energy savings obtainable through recycling have been overemphasized, quantifiable energy conservation benefits should lead to actual cost savings to the producer/contractor, which, in turn, will lead to lower prices for the consumer.

On a 101,000 m^2 (121,000 yd^2) repaving job in Florida (*55*), every effort was made to account for all energy expended. The amount of energy that would have been consumed on an equivalent job using conventional construction methods was estimated. It was found that the conventional method would have used 2.6 trillion joules (2.5 billion BTU) more energy than the HIPR technique. This is equivalent to an energy savings of 32 percent.

CHAPTER SEVEN

GUIDELINES FOR EFFECTIVE USE OF HIPR

A procedure for determining the appropriateness and guiding application of HIPR processes has been developed by Emery (*9*) and others (*15,71,72*). Important aspects related to the technology are outlined in a series of tables modified only slightly from Emery (*9*): general steps (Table 4), preliminary pavement evaluation (Table 5), applicability of the process (Table 5), detailed pavement evaluation (Table 6), selection of best option (Table 7), and quality control (Table 8). These tables are provided merely as generalized guides. It is recognized that special circumstances will arise which are not covered herein.

Where appropriate, agencies should offer the HIPR process selected along with other alternatives to procure the most cost-effective strategy. Currently, the decision of local authorities to use a particular process is often based on contractors convincing them to try their method. Success with a particular method has led some local and state agencies to repeatedly specify the same methods instead of evaluating all possible procedures and then selecting the best for their particular needs (*4*).

PAVEMENT EVALUATION

Evaluation of the existing pavement is an important step in the rehabilitation process and should be given a high priority (*60*). If surface defects such as rutting, cracking, and/or deficient friction exist, the source of the problem needs to be identified before HIPR or any other type of rehabilitation process is initiated. If mixture problems such as moisture susceptibility, excess asphalt, inadequate aggregate interlock, too hard/too soft asphalt can be identified successfully, it may be possible to eliminate the problem using HIPR. If the source of the problem is not identified and corrected, then the problem is likely to manifest itself again after rehabilitation.

MIXTURE EVALUATION

ASTM methods D 4552, "Classifying Hot-Mix Recycling Agents," (*73*) and D 4887, "Preparation of Viscosity Blends for Hot Recycled Bituminous Materials," (*74*) and the proposed standard titled, "Classifying Emulsified Recycling Agents," will be useful in determining the optimum type and quantity of recycling agent. This overall process typically involves extraction and recovery of asphalt from the existing paving mixture to the scarified depth. It is normally desirable to select the type and quantity of rejuvenator that will restore the binder closest to its as-placed

TABLE 4
GENERAL STEPS IN A HOT IN-PLACE RECYCLING PROJECT (After 9)

Step	Further Details	Comments
1. Preliminary Pavement Evaluation	Table 5	Mainly to determine if pavement structure is adequate.
2. Applicability of HIPR	Table 5	If HIPR not applicable, develop alternative rehabilitation or reconstruction method(s).
3. Detailed Pavement Evaluation	Table 6	Mainly quality and properties of existing pavement surface course.
4. Selection of HIPR Option	Table 7	Heater-scarify, remix, repave or remix-repave.
5. a. Remix - Select Rejuvenator (Type and Application Rate), and/or Design New Hot Mix.		Major asphalt technology aspects in conjunction with Step 3.
b. Repave - Specify New Hot-Mix Overlay.	Figure 17	
6. Completion of HIPR Project	Table 8	Quality control important

Note: It is assumed that the appropriate specification preparation, bidding and payment, and quality control have been incorporated in the steps, as required.

TABLE 5
INFORMATION REQUIRED FROM PRELIMINARY PAVEMENT STRUCTURE EVALUATION (After *9*)

Item	Details	Reason
Pavement Inventory Information	• class of pavement • pavement structure[a] • pavement history • traffic volume	• work schedule • applicability of HIPR • supplement detailed evaluation • work schedule
Pavement Structure	• structural defects (types and extent)[a] • non-structural defects (types and extent) • localized structural defects	• applicability of HIPR • selection of HIPR option • need for preliminary localized repairs
Prior Treatments (See Pavement Inventory Also)	• any special treatments or materials (surface treatment, rubberized asphalt, road markings, fabrics, epoxy patching, etc.)	• need for removal (cold milling for instance), if possible, before HIPR process
Geometry and Profile	• width, alignment and gradient • surface profile (rutting and wear)[b]	• applicability of HIPR • need for preliminary treatment (cold milling for instance) before HIPR process
Miscellaneous	• manholes, catch-basins, utility covers, etc. • adjacent (close plants, trees, flammables, etc.	• work schedule, protection, and potential flammable gas counter-measures • work schedule and protective action as necessary

Notes:

a. In general, a pavement with structural defects (i.e., lack of structural capacity and/or inadequate base, beyond localized defects that can be readily repaired) will not be a suitable candidate for HIPR. Pavements with non-structural surface defects (rutting, wearing, cracking, aging, poor frictional characteristics, etc.) are suitable candidates for HIPR.

b. Pavement width, alignment and/or gradient improvement requirements, or excessive rutting and wear (greater than about 50 mm), may preclude HIPR.

rheological properties. Field experience suggests that laboratory tests often indicate more recycling agent than is actually needed. Therefore, adjustments may be required during field operations.

It should be noted that rejuvenator application temperature data (desirable viscosity) have also been developed. It is generally advised that the lowest suitable rejuvenator application temperature be used to avoid evaporative loss during incorporation and mixing (*9*).

CONSTRUCTION

Emery (*9*) states that the average recycled mixture temperature required for satisfactory compaction is in the 105°C to 115°C (221°F to 239°F) range at the breakdown roller, depending on specific site and ambient conditions. Generally, no insurmountable problems have been experienced with achieving specified compaction levels, particularly when the repave option is involved. For

TABLE 6
IMPORTANCE OF INFORMATION FROM DETAILED EVALUATION OF EXISTING PAVEMENT SURFACE (After 9)

Pavement Evaluation Item	Pavement Evaluation Parameter	Surface Defect			
		Wear	Rutting	Cracking	Friction
Surface Condition[a]	• cracks (types and extent)	N	N	M	N
	• transverse profile	M	M	N	R
	• longitudinal profile	R	R	N	N
Existing Asphalt Concrete[b] (usually surface course, but must be at least to proposed scarification depth)	• thickness	M	M	M	M
	• asphalt-cement content (for scarification depth)	M	M	M	M
	• grading (for scarification depth)	M	M	M	M
	• density	M	M	M	M
	• air voids	M	M	M	M
	• penetration, viscosity and softening point of recovered asphalt cement (for scarification depth)	M	R	M	N

M - Mandatory   R - Recommended   N - Not Necessary

Notes: a. Information should be representative of the pavement section involved, with special areas (extensive patching, for example) and localized structural distress areas noted.

b. Typically based on a coring program. Cores should be representative of pavement section involved, with additional cores taken as necessary for special areas.

the scarification of the old asphalt concrete to be effective and efficient, experience has shown that it is desirable for the minimum temperature at the depth of scarification to be the softening point for the project's recovered asphalt cement before rejuvenation.

SPECIFICATIONS

Careful consideration must be given to preparing specifications that are relevant to the intended construction program. The specifications must clearly describe the desired finished product. In some cases, it may be necessary to describe the type of equipment that will provide an acceptable finished product, but this may limit the number of potential contractors. It is advisable to specify that the application rate of the recycling agent and any virgin bituminous mixture must be related directly to the forward movement of the equipment to minimize variation during speed changes and stoppages.

Guideline specifications from the ARRA and examples of HIPR state specifications from Arkansas, California, Idaho, Iowa, Ohio, and Texas are provided in Appendices B through G. These were selected from the 18 states that have a specification because they offered a variety of regulations.

CONSTRUCTION QUALITY CONTROL

Quality control for HIPR construction should be similar to that used for conventional hot-mix asphalt pavement construction. Items of interest include patching of existing pavement, mixture temperature, compacted density, surface smoothness, cross slope, handwork, mat depth, and general mat appearance (texture, tearing, checking, too much or too little asphalt). Excessive smoke or flames on pavement should not be tolerated.

Some states require construction of a test strip to ensure the process is functioning properly before commencing operations. A generic repaving specification supplied by Cutler (*75*) states,

> the contractor, at his own expense, shall successfully verify his ability to heat and scarify to the depth shown on the plans in a 500-foot control section. The gathering (of RAP), addition of rejuvenating agent, mixing, leveling, and placing of new surfacing will also be accomplished during the test. Immediately after scarification, the Engineer shall, in at least four randomly pre-selected locations, determine the depth of scarification. Continuous testing and retesting shall not be allowed. If after two successive tests, the results are inconclusive or are not in specification, the contractor shall make necessary adjustments or modifications and notify the Engineer who shall conduct one additional test for conformance. If the results of this test are inconclusive or out of specification, the equipment or processes shall not be used.

TABLE 7
HOT IN-PLACE RECYCLING PROCESS OPTIONS (After 9)

Purpose[a]	Option	Process
To improve the profile of a surface course deformed by rutting or wearing, but in comparatively unaged condition with minor cracking.[b]	Heater-Scarify	Heating, Scarification, Rejuvenator (if needed), Levelling, Reprofiling[c], Compaction[d]
To improve the profile of surface course severely deformed by rutting or wearing, with new hot-mix overlay placed in one pass. To improve frictional characteristics. To provide some pavement strengthening.	Repave	Heating, Scarification, Rejuvenation, Levelling, Laying New Hot Mix[f], Reprofiling, Compaction[d]
To improve the quality of old, cracked, aged surface course by the addition of rejuvenator and/or new hot mix.[e]	Remix	Heating, Scarification, Rejuvenator, Mixing and/or New Hot Mix, Mixing, Levelling, Reprofiling, Compaction[d]

Notes:
a. Primary purpose given in each case.
b. Often used prior to hot-mix resurfacing (heater/ scarification).
c. Standard screed and screed controls.
d. Standard compaction equipment and procedures.
e. The composition, grading, and/or asphalt-cement content of the new hot mix can be adjusted to improve the quality of the old mixture.
f. Standard augers and auger controls.

New York DOT remixing specifications require that the contractor sample, test, and supply test results of the recycled loose mixture (*76*). The specification states,

> the loose material is then tested for Marshall stability, flow, air voids, gradation, and asphalt content. Three samples shall be tested at the start of the project. Any time there is a change in the virgin hot-mix asphalt or the rate of usage, two samples of the recycled loose mixture shall be tested. Each day, during routine production, one sample shall be taken from each 0.8 km (half mile) recycled or fraction thereof. One of these daily samples shall be tested and the remaining samples shall be retained until the acceptance of the project.

TABLE 8
QUALITY CONTROL FOR HOT IN-PLACE RECYCLING PROCESS[a] (After 9)

Item	Recommended Method[b]
Width	• As usual
Depth of Scarification	• Measure depth from existing surface adjacent to second mixer or • Use circular ring method[c]
Rejuvenator Application Rate (if any)	• ASTM D 4887 (*49*) • Calculate from quantity used
Rejuvenator Quality (if any)	• As usual (specifications and ASTM D 4552) (*48*)
New Mixture Addition Rate (if any)	• Calculate from quantity used (tons) and in-place density
Thickness of New Hot-Mix Overlay (if any)	• Calculate from quantity used (tons) and in-place density
Temperature at Breakdown Rolling	• Monitor at mid-point of re-profiled depth
Temperature of New Hot-Mix (if any)	• As usual
Asphalt Cement Content, Gradation, and Stability Requirements	• As usual
Compaction	• As usual. Important to compare to relevant re-compacted density
Surface Tolerance	• As usual
Penetration/Viscosity and Softening Point of Asphalt Extracted from Recycled Mixture	• As usual

Notes:

a. As the HIPR processes are largely based on conventional hot-mix paving technology, it is only necessary to supplement the usual quality control requirements. The quality control items and frequency of testing should be established at the level necessary to ensure specification compliance.

b. All testing should be done on random, representative samples, by qualified technicians in a certified laboratory.

c. A ring of known internal diameter (typically, 355 mm = 0.1 m^2 area) is pushed into the scarified old pavement as deeply as possible, the scarified old mixture within the ring is removed and its mass determined, and from the bulk relative density of the old pavement the depth of scarification is calculated.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- When recycling a pavement to address a performance problem, the source of the problem must be identified and corrected or the problem is likely to manifest itself again after rehabilitation.
- There are three basic types of HIPR: heater-scarification, repaving, and remixing. Specialized equipment is commercially available to perform each type in a single pass or in multiple passes.
- Remixing or repaving provides mixtures suitable for use as pavement surfaces on high-volume highways, streets, and airports. Heater-scarification alone can provide an acceptable intermediate or leveling course but is not normally acceptable as a surface course. An overlay on heater-scarified pavements is usually recommended.
- Single-pass HIPR processes can be used to minimize traffic disruptions. Time required for lane blockages is less than for conventional pavement rehabilitation methods. Safety is enhanced since motorists do not have to contend with a pavement-edge dropoff for long periods.
- HIPR is a viable and economic rehabilitation alternative for asphalt pavements, particularly those with a thickness of at least 75 mm (3 in.) of hot-mix asphalt. The candidate pavement must be structurally sound, because HIPR is limited to surface rehabilitation.
- In urban areas, HIPR offers a pavement rehabilitation alternative where drains, curbs, manholes, overpasses, shoulders, and other height-sensitive structures may cause problems for conventional rehabilitation processes.
- Careful consideration must be given to preparing specifications that are relevant to the intended construction program. The specifications must clearly describe the desired finished product. In some instances, it may be necessary to describe the type of equipment that will provide an acceptable finished product (such as a pugmill to ensure adequate mixing of new material or a mechanism to ensure the appropriate quantity of recycling agent is added). Conventional gradation requirements, engineering properties, and compaction requirements should be used when specifying HIPR or permitting it as an alternative. Excellent specifications and quality control guidelines have been developed by selected highway and airport authorities.
- For HIPR projects, greater than normal resources may be required for both inspection and materials testing. This is partly because the process is relatively new and partly because it offers more opportunities for variability than conventional paving processes. HIPR equipment is inherently complex and is built in such a way that many of the operations cannot be readily observed. Inspectors should be trained to analyze the consequences of various mechanical failures and operational malfunctions. Items specifically associated with HIPR might include the consistency of the pavement being recycled (ensure proper mixture design), preheating operations (avoid charring asphalt), the recycling depth, and sampling and testing to ensure proper rejuvenation and no overheating.
- Strength equivalencies used in the pavement design process should be essentially the same as those normally assigned to a similar standard mixture produced by conventional processes.
- The maximum recycling depth for most successful HIPR operations is 50 mm (2 in.); however, in Canada, where soft asphalts are normally used, two machines in tandem have achieved depths up to 75 mm (3 in.) (*20*). Machines with rotary milling heads can typically cut deeper than those with stationary scarifier teeth.
- Mean viscosity of the recovered binder from recycled mixtures can be closely controlled; however, considerable variation in viscosity throughout the job may result. Variations in viscosity of the recovered recycled binder that exceed variations in the viscosity of the recovered binder in the original pavement may indicate that the machine is being driven too fast. Failure to test the viscosity of binder recovered from the recycled mixture may permit premature hardening of the asphalt and thereby decreased performance.
- Sometimes it is difficult to add enough rejuvenator without overasphalting the mixture.
- In cool climates or in winter, HIPR at night has sometimes been impractical because of low ambient and pavement temperatures.
- Excess asphalt mastics used for joint and crack filling operations can create flare-ups under the preheater. This has been successfully addressed by using a conventional garden fertilizer spreader to distribute a strip of hydrated lime 1-mm to 2-mm thick or sand along the heavily filled cracks, which reduced the flare-ups. In some cases, the crack sealant material was removed prior to recycling.
- HIPR is acceptable on roads with one seal coat; however, two or three seal coats at the surface may cause the material to smoke and even catch fire. Furthermore, the seal coats act as insulation that prevents heat from penetrating to the pavement below.
- Direct flame contact with the existing pavement surface should be avoided because this has caused excessive hardening and even charring of the asphalt. Some agencies specify indirect or radiant preheating when HIPR is used.
- Many owner agencies specify a pugmill for the remixing process to ensure complete and uniform mixing of the RAP, rejuvenator, and virgin materials.
- Typical average HIPR construction rates may range from 610 to 2,800 lane-m/day, depending on depth of scarification, pavement materials, ambient temperature, recycling equipment, and traffic.
- The ideal candidate for HIPR is a pavement that is not too old and not excessively oxidized. The existing asphalt cement must be capable of being rejuvenated to its original, as-placed consistency.

• None of the HIPR methods currently in use are designed to provide major corrections in grade. They can smooth out some surface irregularities such as rutting or corrugations, but they cannot remove large undulations due to volume changes in the base or subgrade.

• When all factors are considered, a savings of 10 percent to 50 percent can be achieved when a 25-mm (1-in.) HIPR layer is compared with a new 25-mm (1-in.) overlay. Benefit-cost data for HIPR pavements are scarce.

• HIPR is acceptable to the driving public because of the increased awareness of the need to conserve natural resources; and, with HIPR, drivers can see the old pavement virtually turn into a new pavement.

• Some HIPR operations have caused concern about air pollution, particularly in urban areas. Major advancements toward reduced emissions have been made in recent years.

New developments in the highway industry often follow a pattern of enthusiastic acceptance followed by diminishing interest based on isolated failures or less than spectacular benefits. HIPR is no different. Unanticipated problems will occur and adjustments will have to be made. Currently, highway agencies can specify and the recycling industry can supply high quality HIPR asphalt mixtures. It would be unfortunate if factors such as specifier conservatism, isolated failures, or lack of technical guidance continue to limit asphalt recycling by some agencies when it is clear that asphalt recycling is technically sound and environmentally favorable in many instances.

RECOMMENDATIONS

• General HIPR specifications should allow for all three methods, i.e., heater-scarification, repaving, and remixing. This gives more versatility to the planning engineer and a higher probability of cost-effectively solving a particular problem. Whenever feasible, HIPR should be allowed as an alternative rehabilitation method.

• To maximize the probability of uniform percentages in the recycled mixture, equipment that gears the application rate of the recycling agent and virgin bituminous mixture (if any) to the forward movement of the applicator should be specified.

• Specifications should require indirect or radiant heating by preheaters. Radiant heat should be defined in the specification as that which does not permit direct contact of flame with the pavement surface.

• The same quality control tests for hot-mix asphalt plant production should be performed for HIPR production. They include quality control tests on aggregate gradation, asphalt-cement content, and compacted density (air void content) of recycled materials. Quality control tests should also include recovering of binder from the recycled mixture and measuring absolute viscosity and penetration.

• The contractor should furnish a representative responsible for observing and adjusting the infrared heaters as they pass over the existing pavement to reduce overheating and thus reduce excessive hardening of the asphalt cement.

• The industry should use consistent terminology to describe the three different HIPR processes currently in use and other associated items. A suggested glossary for often misused terms is provided after this section.

RESEARCH NEEDS STATEMENTS

This study of the state of the art of HIPR has revealed that the process is worthy of further investigation in certain areas.

• An overall physical characterization of in-place recycled hot mix as compared with conventional hot mix is needed. The study should address comparative resistance to rutting and cracking as well as durability, moisture susceptibility, and importance of the bond at the interface between the old and new pavement layers.

• Life-cycle costs (first costs, life cycles, required rehabilitation periods, and maintenance alternatives) for HIPR should be better defined and compared with other maintenance and rehabilitation alternatives.

• When recycling agents are used, proper curing techniques and even the importance of proper curing of hot recycled asphalt mixtures are unknown. How long do properties of mixtures change after final compaction? Are the changes significant? What time period should be required between compaction and testing in the laboratory? What laboratory curing procedure best simulates field conditions? Answers to these questions are needed.

• Heating and mixing of the existing pavement during HIPR significantly increases the viscosity of the asphalt cement. Further studies of field data compared with laboratory prediction and accurate mixture temperatures and temperature profiles within the preheated layer should be conducted to develop guidelines to deal with asphalt hardening directly attributable to the HIPR process.

• Mixture design of HIPR surfaces should be based on the most up-to-date and mechanistically correct methodology available. Although many HIPR surfaces are too thin for rutting to be a major concern, 50-mm (2-in.) to 75-mm (3-in.) recycled pavements require such an analysis. Mixture design procedures developed under the AAMAS and the SHRP should be studied to determine their applicability to HIPR. Furthermore, the influence of stress distribution in the HIPR layer as influenced by the degree of bond developed between the overlay and the base should be evaluated when deciding on the appropriate laboratory test loading conditions to simulate field stress states.

• Comprehensive guidelines for the overall HIPR process need to be developed to aid maintenance engineers and design engineers in their decision-making process. The following should be addressed: optimum point during a pavement's service life to perform HIPR, preparation of specifications, types of pavements that are and are not viable candidates for HIPR, selection of type and quantity of recycling agent, mixture design and structural design specifically for HIPR, selection of optimum HIPR method, quality control, and quality assurance.

• Air pollution associated with HIPR should be investigated. When compared with conventional processes, determination of the total air pollution generated should consider the production and transportation of new materials that would have been used in place of the recycled materials.

• Since the use of asphalt rubber in pavements has been mandated by the federal government, research should determine the effects of HIPR on asphalt-rubber pavements.

REFERENCES

1. The Asphalt Institute, "The Asphalt Handbook," Manual Series No. 4 (MS-4), Lexington, Kentucky (1989).
2. National Asphalt Pavement Association, "Hot Recycling of Yesterday," Recycling Report, Vol. 1, No. 2, (September, 1977).
3. Epps, J. A., "State-of-the-Art Cold Recycling," Transportation Research Record No. 780, Transportation Research Board, National Academy of Sciences, Washington, D.C. (1980).
4. Shoenberger, J. E. and Voller, T. W., "Hot In-Place Recycling of Asphalt Pavements," Technical Report GL-90-22, Department of the Army Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi (September 1990).
5. Epps, J. A., "Cold-Recycled Bituminous Concrete Using Bituminous Materials," Synthesis of Highway Practice No. 160, National Cooperative Highway Research Program, Transportation Research Board (July 1990).
6. Finn, F. N., "Seminar on Asphalt Pavement Recycling Overview of Project Selection," Transportation Research Record No. 780, Transportation Research Board, National Academy of Sciences, Washington, D.C. (1980).
7. Burgin, E. W., "Asphalt Pavement Recycling and Rejuvenation," *Proc.*, The 32nd Annual Conference of Canadian Technical Asphalt Association, Vol. XXXII (November 1987), pp. 2–13.
8. Asphalt Recycling and Reclaiming Association, "Hot In-Place recycling—First in the Line of Pavement Maintenance," Hot In-Place Recycling Technical Committee, Annapolis, Maryland, 1992.
9. Emery, J. J., Gurowka, J. A., Hiramine, T., "Asphalt Technology for In-Place Surface Recycling Using the Heat Reforming Process," *Proc.*, The 34th Annual Conference of Canadian Technical Asphalt Association, Vol. XXXIV (1989).
10. Whitney, G. F., "America's Recycling Future: ARRA's View," *Rural and Urban Roads* (March 1980).
11. Carmichael, T., Boyer, R. E. and Hokanson, L. D., "Modeling Heater Techniques for In-Place Recycling of Asphalt Pavements," *Proc.*, Association of Asphalt Paving Technologists, Vol. 46 (1977), pp. 526–540.
12. Whitney, G. F., "Urban Surface Recycling," Transportation Research Record No. 780, Transportation Research Board, National Academy of Sciences, Washington, D.C. (1980).
13. Lawing, R. J., "Use of Recycled Materials in Airfield Pavements Feasibility Study," Report No. AFCEC-TR-76-7, Air Force Civil Engineering Center, Tyndall Air Force Base, Florida (1976).
14. Scrimsher, T., "Recycling Asphalt Concrete on State Route 36," Report No. FHWA/CA/TL-81/03, California Department of Transportation, Sacramento, California (1981).
15. Asphalt Recycling and Reclaiming Association (ARRA), "Guideline Specifications for Hot In-Place Recycling," Annapolis, Maryland (1988).
16. Nittinger, R. J., "Asphalt Recycling Opens New Doors to Savings," *Roads and Bridges*, Vol. 24, No. 10 (October 1986).
17. Rathburn, J. R., "One-Step Repaving Speeds Country Work," *Roads and Bridges* (March 1990).
18. Hudson, S., "Experimental Paving on Alabama's U.S. 78," *Dixie Contractor* (November 1989).
19. Doucet, R. J., Jr. and Paul, H. R., "Wirtgen Remixes Surface Recycling," Report No. FHWA/LA-91/235, Louisiana Transportation Research Center, Baton Rouge, Louisiana (February 1991).
20. Kuennen, T., "Hot In-Place Recycling Gets Nod in Provinces," *Roads and Bridges*, Vol. 27, No. 10 (October 1989).
21. Kuennen, T., "Hot In-Place Recycling Revitalizes Texas Road," *Roads and Bridges*, Vol. 28, No. 10 (October 1990).
22. Balchunas, K., "Pavement Maintenance and Hot In-Place Recycling," *Proc.*, Third IRF Middle East Regional Meeting, Riyadh, Saudi Arabia, February (1988).
23. "The Truth About Remixing Asphalt," *Better Roads* (December, 1987).
24. Robb, C., "It's All in the Mix," *Construction News*, Southham Company (June 1990).
25. Fletcher, M. O., "Asphalt Paving Recycling Utilizing the Wirtgen Remixer Process," Research and Materials Laboratory, South Carolina Department of Highways and Public Transportation (September 1984).
26. Patyk, S., "Road Mixer Revitalizes Texas Asphalt Pavement," *Roads and Bridges*, Vol. 27, No. 10 (October 1989).
27. Al-Ohaly, A. A. and Terrel, R. L., "Effect of Microwave Heating on Adhesion and Moisture Damage of Asphalt Mixtures," Transportation Research Record No. 1171, Transportation Research Board, National Research Council (1988), pp. 27–36.
28. Terrel, R. L. and Al-Ohaly, A. A., "Microwave Heating of Asphalt Paving Materials," *Proceedings*, Association of Asphalt Paving Technologists, Vol. 56 (1987).
29. "Microwaves Offer Maximum Potential," *Better Roads*, Vol 52, No. 9, September (1982), pp. 16–17.
30. Southwestern Laboratories, Inc., "Crumb Rubber Modified (CRM) Asphalt Use in Recycling In Situ Pavements," for Cutler Repaving, Inc., Houston, Texas (1992).
31. "Asphalt Recycling Innovations: Warm Mix Leads the Way," *Better Roads*, Vol. 58, No. 7, July 1988, pp. 23–26.
32. Kuennen, T., "Hot In-Place Recycling Specs Developed by ARRA," *Roads and Bridges*, Scranton Gillette Communications, Vol. 26, No. 10, October (1988), p. 72.
33. Baker, J., "Economics Prompt Texans to Use In-Place Recycling," *Roads and Bridges*, Vol. 25, No. 10 (October 1987).
34. "In-Place Recycling Rids Roads of Ruts," *Roads and Bridges*, Vol. 25, No. 10 (October 1987).
35. "Hot In-Place Recycling Saves Texans Money," *Roads and Bridges*, Vol. 24, No. 10 (October 1986).
36. "Aging Asphalt Runway Gets In-Place Rehab," *Roads and Bridges*, Vol. 25, No. 1 (January 1987).
37. Klemens, T. L., "Upgrading IH-10 to First Class," *Highway and Heavy Construction* (September 1991).
38. Emery, J. J., "Asphalt Concrete Recycling in Canada," *Proc.*, 36th Annual Conference of Canadian Technical Asphalt Association, Vol. XXXVI (1991).
39. Colorado State Department of Highways, Revision of Section 405, Specification for Heating and Remixing Treatment, Denver, Colorado (1990).

40. Iowa Department of Transportation, Standard Specifications for Highway and Bridge Construction, Specification No. 2309.02 Surface Recycling by Hester Scarifyer, Ames, Iowa (1984).
41. Taverner, G., Thompson and Doering, W., "Hot In-Place Recycling of Airfield Pavements at Canadian Forces Base Edmonton, Alberta," *Proceedings*, 35th Annual Conference of Canadian Technical Asphalt Association, Vol. XXXV (November 1990), pp. 60–79.
42. Perry, G. M., "Repaving...One More Time," *Southwest Contractor*, Year 52, No. 10 (June 1990).
43. Epps, J. A., Little, D. N., Holmgreen, R. J., and Terrel, R. L., "Guidelines for Recycling Pavement Materials," NCHRP Report 224, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C. (September 1980).
44. Von Quintus, H. L., Scherocman, J. A., Hughes, C. S., and Kennedy, T. W., "Asphalt Aggregate Mixture Analysis System (AAMAS)," NCHRP Report 338, National Cooperative Highway Research Program, Transportation Research Board, National Research Council (March 1991).
45. The Asphalt Institute, "Asphalt Hot-Mix Recycling," Second Edition, Manual Series No. 20, Lexington, Kentucky (August 1986).
46. Kari, W. J., Santucci, L. E., and Coyne, L. D., "Hot Mix Recycling of Asphalt Pavements," *Proc.*, Association of Asphalt Paving Technologists, Vol. 48 (1979).
47. Kallas, B. F., "Flexible Pavement Mixture design Using Reclaimed Asphalt Concrete," Research Report 84-2, Asphalt Institute, Lexington, Kentucky (October 1984).
48. Scherocman, J. A., "Hot-Mix Asphalt Paving Handbook," UN-13 (CEMP-ET), U.S. Army Corps of Engineers, Washington, D.C. (1991).
49. American Society for Testing and Materials, "Standard Test Method for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures," ASTM D 2172, Philadelphia, PA (1991).
50. American Society for Testing and Materials, "Standard Test Method for Recovery of Asphalt from Solution by Abson Method," ASTM D 1856, Philadelphia, PA (1991).
51. American Society for Testing and Materials, "Test Method for Recovery of Asphalt from Solution Using the Rotavapor Apparatus," Proposed Method, Philadelphia, PA (1991).
52. Sousa, J. B., Harvey, J., Painter, L., Deacon, J. A., Monismith, C. L., "Evaluation of Laboratory Procedures for Compacting Asphalt-Aggregate Mixtures," Report TM-UCB-A-003A-90-5, Strategic Highway Research Program, University of California, Berkeley, California (August 1990).
53. Carey, D. E. and Paul, H. R. "Surface Recycling of U.S. 61 from Norco to Jefferson Parish Line," Research and Development Section, Louisiana Department of Transportation (August 1980).
54. Johnson, J. K., "Results of Hot In-Place Recycling at Thompson Field," Interagency Memorandum/Report, Aviation Office, Florida Department of Transportation (May 23, 1991).
55. Potts, C. F. and Murphy, K. H., "Surface Recycling of Asphalt Concrete Pavements," Materials Research Office, Florida Department of Transportation, Gainesville, Florida (September 1979).
56. Paul, H. R., "Surface Recycling Route U.S. 71 Construction and Initial Evaluation," Report No. FHWA/LA-86/189, Louisiana Transportation Research Center, Louisiana Department of Transportation and Development (August 1986).
57. Breckwoldt, E. J., Lyon, Jr., J. W. and Shah, S. C., Intradepartmental Correspondence on S. P. Numbers 826-04-09 and 836-05-04, Louisiana Department of Transportation and Development (June 4, 1980 and February 26, 1981).
58. Lane, K. R., "Placement of an Experimental Heater-Scarified In-Place Recycled Pavement," Report No. FHWA-CT-RD-647-2-81-14, Connecticut Department of Transportation Wethersfield, Connecticut (November 1981).
59. Ganung, G. A., "Performance Evaluation of Heat-Scarified In-Place Recycled Bituminous Pavement, Rt. 15, Westport," Report No. FHWA-CT-RD 647-5-87-2, Division of Research, Connecticut Department of Transportation (May 1987).
60. Fyvie, K. R. and Valkenburg, J. V., "Hot In-Place Recycling of Runway 15-33 Prince George Airport, B. C. - A Case Study," *Proc.*, 34th Annual Conference of Canadian Technical Asphalt Association, Volume XXXIV (November 1989), pp. 258–277.
61. Fletcher, M. O., "Asphalt Pavement Recycling Using the Wirtgen Remixer Process," Research and Materials Laboratory, South Carolina Department of Highways and Public Transportation (September 1984).
62. Goodsall, D. A., "In Situ Recycling of Asphalt Wearing Courses in the UK," Special Report 65, Transport and Road Research Laboratory, Berkshire, England (1981).
63. Thompson, E. A., "Chemical Aspects of Asphalt Pavement Rejuvenation," *Proc.*, Canadian Technical Asphalt Association, November (1981), pp. 84–96.
64. Page, G. C., "Florida's Experience in Hot-mix asphalt Recycling," *Hot-mix asphalt Technology*, Spring (1988), pp. 10–16.
65. Ameri-Gaznon, M. and Little, D.N., "Octahedral Shear Stress Analysis of and ACP Overlay on a Rigid Base," *Proc.*, Association of Asphalt Paving Technologists, Vol. 59 (1990).
66. Marini, R., "New Recycling Technology from Asphalt Pavements," *Proc.*, Third Eurobitume Symposium, The Hague, Netherlands, September (1985).
67. Bandyopadhyay, S.S., "Structural Performance Evaluation of Recycled Pavements by using Dynamic Deflection Measurements," Transportation Research Record No. 888, Transportation Research Board, Washington, D.C. (1982).
68. Taylor, M. and Dillmann, E., "Airport Saves With Hot In-Place Recycling," *Public Works*, Vol. 119, No. 10 (1988), pp. 118–119.
69. Marini, R., "Considerations on Hot Mix Recycling of Asphalt Pavements in the Domain of Road Maintenance," *Proc.*, Third IRF Middle East Regional Meeting, Riyadh, Saudi Arabia, Feburary (1988).
70. Servas, V.P., "Resource and Energy Savings Through the Recycling of Bituminous Pavement Materials," *Proc.*, PTRC Summer Annual Meeting, University of Warwick, England, July (1981), pp. 107–117.
71. Taisei Road Construction Co., "Technical Guide for the Heat Reforming Process," Ltd., Tokyo, Japan (1984).
72. "Heat Reforming Process No. 5 System," Taisei Rotec, Inc. (1987).
73. American Society for Testing and Materials, "Standard Practice for Classifying Hot Mix Recycling Agents," ASTM D 4552, Philadelphia, PA (1991).
74. American Society for Testing and Materials, "Standard Test Method for Preparation of Viscosity Blends for Hot Recycled

Bituminous Materials," ASTM D 4887, Philadelphia, PA (1991).
75. Cutler Repaving, Inc., "Hot In-Place Repaving Specification," a generic guideline specification, Lawrence, Kansas (1991).
76. Materials Bureau, "Item 19403 — Asphalt Concrete Hot In-Place Recycling Specification," New York Department of Transportation, Albany, New York (February, 1992).

GLOSSARY

Heater-planer—a device that heats the pavement surface and uses a stationary or vibrating flat steel blade or plate to shear off up to 25 mm of the heated surface.

Heater-scarifier—a device that heats the pavement surface and uses stationary steel tines or teeth to rake off up to 25 mm of the hot surface.

Hot miller—a device that heats the pavement surface and uses a rotating drum that has cutting tips mounted over the cylindrical surface to mill off up to 50 mm of the hot surface.

Surface recycling—a general term that describes all types of in-place recycling of the upper portion of an asphalt pavement whether hot or cold.

Hot in-place recycling (HIPR)—any process used to correct asphalt-pavement surface distress by mechanically removing the pavement surface, heating the excavated material, possibly mixing it with recycling agent or virgin materials, and replacing it on the pavement without removing the recycled material from the original pavement site. This includes both single-pass and multiple-pass methods.

Reclaimed asphalt pavement (RAP)— removed and/or reprocessed pavement materials containing asphalt and aggregates.

Reclaimed aggregate material (RAM)—removed and/or reprocessed pavement materials containing no reusable binding agent.

Scarification—removal of the top 25 mm to 50 mm (1 in. to 2 in.) of an asphalt pavement using a bank of non-rotating teeth. The teeth may be spring loaded thus allowing them to pass over appurtenances in the roadway.

Infrared heating—sometimes referred to as radiant or indirect heating. Involves heating a pavement using invisible heat rays having wavelengths longer than those of red light, thus avoiding direct contact of flame on the pavement surface.

Asphalt rejuvenator—a liquid petroleum product, usually containing maltenes, added to asphalt paving material to restore proper viscosity, plasticity, and flexibility to the asphalt cement.

Recycling agent—a petroleum product ranging from a maltene-based material to an asphalt-based material that is added to RAP to restore desirable viscosity, plasticity, and flexibility to the asphalt cement.

Microwave—short electromagnetic waves, between 30 cm and 1 mm in wave length sometimes used to heat asphalt paving mixtures for recycling.

BIBLIOGRAPHY

Stock, A. F., "Recycling Road Pavements—Techniques and Opportunities," *Proceedings*, PTRC Transport and Planning Summer Annual Meeting, Volume P293 Bath University, England (September 1987).

Abe, Y., Tatsushita, F., Abe, T., Ozawa, K., "Maintenance and Rehabilitation Technologies of Heavy Traffic Road Pavements in Tokyo," *Proceedings*, Second International Conference on Bearing Capacity of Roads and Airfields, Plymouth, England (September 1986).

Kuennen, T., "Los Angeles Paver, Mills with Own Forces," *Roads and Bridges*, Vol. 26, No. 1 (January 1988), pp. 64–65.

Battiato, G., "Heat Propagation in Pavements — A Physics — Mathematical Model for the Optimization of Heating Systems During Recycling in Situ," *Autostrade*, Vol. 27, No. 2, Italian (February 1985), pp. 18–32.

Servas, V. P., "Hot In Situ Recycling," National Institute for Road Research, Civil Engineer in South Africa, Vol. 24, No. 10, October, Pretoria, South Africa (1982), pp. 527–553.

Donnelley, R. H., "New Developments in Highway Equipment," *World Construction*, Vol. 37, No. 2 (February 1984), pp. 49–52.

Ridout, G., "Technology Changes the Face of Britains Highways," *Contract Journal*, Vol. 312, No. 5396, IPC Building and Contract Journals (March 1983), pp. 14–19.

Servas, V. P., "Hot Surface Recycling," *Highway Engineer*, Vol. 28, No. 12, Whitehall Press Limited (December 1981), pp. 8–13.

Dinnen, A., "Recycling—A Summary of Current Methods," Shell Bitumen Review, No. 59, Shell International Petroleum Co. Limited (June 1981), pp. 15–18.

Myers, D. E., "In-Place Recycling and Reconstruction of Flexible Pavements," *Public Works*, Vol. 110, No. 2 (February 1979), pp. 68–71.

Jones, G. M., "In Situ Recycling of Bituminous Pavements," Proceedings, 15th Paving Conference, University of New Mexico, Albuquerque (1978), pp. 36–40.

Epps, J. A., "Waste Materials, By-Products, and Recycled Products, Special Report No. 166, Transportation Research Board (1976), pp. 48–53.

Epps, J. A. and O'Neal, R. J., "Engineering Economy and Energy Considerations Recycling Pavement Materials," Research Report 30, Texas Transportation Institute, Texas A&M University (1975).

Holmgreen, R. J., Epps, J. A., Little, D. N., and Button, J. W., Report FHWA/RD-82/010, Federal Highway Administration, Washington, D.C. (1982).

Jiminez, R. A., "State-of-the-Art Surface Recycling," Transportation Research Record No. 780, Transportation Research Board, National Academy of Sciences, Washington, D.C. (1980), pp. 40–50.

Servas, V. P., "Roads-Remixing," Civil Engineering, Morgan-Grampion Professional Press Limited (July 1980).

Mosch, K., "How Economical is the Repave Method?," Bertelsmann-Fachverlag, Tiefbau, Engenieurbau Strassenbau, Vol. 20, No. 3 (March 1978), pp. 191–198.

Beaty, R. W. and Binz, L. V., "Hot Process Recycling of Asphalt Pavement Materials—State-of-the-Art," Society of Automotive Engineers Annual Meeting (1979).

Little, D. N., Holmgreen, R. J., and Epps, J. A., "Effect of Recycling Agents on the Structural Performance of Recycled Asphalt Concrete Materials," *Proc.*, Association of Asphalt Paving Technologists, Volume 50, (1981).

APPENDIX A

QUESTIONNAIRE

Hot in-place recycling (HIPR) is defined as a process of correcting asphalt pavement surface distress by mechanically removing the pavement surface, heating the excavated material, possibly mixing with virgin materials, and replacing on the pavement without removing the recycled material from the original pavement site.

The objective of this study is to assemble available information on HIPR and prepare an NCHRP Synthesis.

1. Location of state:

2. Name, title and, address, and phone no. of person contacted:

____

____

3. To what extent do you use <u>hot</u> in-place recycling (no. of jobs):

   None-_____ Experimental-_____ Less than 5/yr-_____ More than 5/yr-__

   Estimated total tonnage-_________

   If not, why not-____________________________________

4. What methods have been used in your state? (give examples)____________

____

5. What is the preferred method?____________________________

   Milling depth range-______________________________

6. Does your state have written specifications for HIPR?-______________ (if so, request a copy)

   If not, how do you specify to contractor? ______________________

____

7. What procedure is followed to determine a mixture design?____________

____

   (if they have a written method, request a copy)

8. What procedures are followed to maintain quality control?

   a. Binder content-______________________________

   b. Aggr gradation-______________________________

   c. Density-___________________________________

   d. Test strip-_________________________________

9. For what class of highways is HIPR normally used?

   Major-_____ Secondary-_____ Low Volume-_____

10. Is a new surface layer or seal normally placed over a HIPR pavement?

   What is most common?-______________________________

11. How would you categorize performance of HIPR pavements in your state?

   Excellent-_____ Good-_____ Fair-_____ Poor-_____

12. What problems have been associated with HIPR? ________________

____

13. Have you recycled asphalt-rubber pavements?______________

   Results? __________________________________

14. What structural layer equivalency is typically applied to the HIPR layer?

____

15. Are additives or admixtures normally used with HIPR? ____ If so, what?

____

16. Is HIPR life-cycle cost information available from your state? ______

   If so, request copy.

17. Are research reports on HIPR or case studies available from your state?

   If so, request copies.

APPENDIX B

GUIDELINE SPECIFICATIONS FOR HOT IN-PLACE RECYCLING BY THE ASPHALT RECYCLING AND RECLAIMING ASSOCIATION

INTRODUCTION

Hot In-Place Recycling is an on-site, in-place method that rehabilitates deteriorated bituminous pavements and thereby minimizes the use of new materials.

This process may be performed as either a single pass (one phase) operation that monolithically recombines the restored pavement with virgin material, or as a two pass procedure, wherein the restored material is recompacted and the application of the new wearing surface then follows a prescribed interim period that separates the process into two distinct phases.

Hot In-Place Recycling provides a very low cost maintenance strategy that enables the public works official to effectively re-use existing materials. This process demonstrates that asphalt is a rather unique construction material in deteriorated pavement with inordinate depths of new material conventionally applied, or lose it to the grinder, proponents of Hot In-Place Recycling encourage restoration.

Hot In-Place Recycling effectively addresses the classic symptoms of deteriorated pavement:

- Cracks are interrupted and filled.
- Aggregate stripped of the bitumen is remixed and recoated.
- Ruts and holes are filled, shoves and bumps are leveled, drainage and crowns are re-established.
- Flexibility is restored by chemically rejuvenating the aged and brittle pavement.

- Aggregate gradation and asphalt content may be modified by some variations of this process.
- Enhance highway safety through improved skid resistance.

In a period of rapidly increasing costs and limited funding, hot in-place recycling presents the opportunity to spread available dollars over a much greater area. Roadway deterioration can be suspended, pavements preserved and upgraded, and costly reconstruction avoided.

Note: These guideline specifications are meant for the promotion of Hot In-Place Recycling and to provide reasonable assurance to the awarding authority that quality work will be performed by the recycling contractor.

PRE-BID CONSIDERATIONS

1. Many asphalt pavements are appropriated to Hot In-Place Recycling. Pavement characteristics, relative to depth, mix design, and base stability, should be considered in the selection process.
2. Preliminary evaluation of the deteriorated pavement should be performed in the company of qualified recycling specialists to verify that the degree of distress is within the capabilities of this process for effective restoration. Localized distortions, failures, or concentration of contaminants may require advance treatment to qualify as a potential candidate.

   A request issued to interested recycling contractors listing basic data, questions, and expectations will be particularly useful, as a means for securing professional input, to agencies unfamiliar with recycling projects.
3. Surface courses containing unusually large aggregate, i.e., one-inch, may not be suitable for Hot In-Place Recycling.

- Aggregate gradation and asphalt content may be modified by some variations of this process.
- Enhance highway safety through improved skid resistance.

In a period of rapidly increasing costs and limited funding, hot in-place recycling presents the opportunity to spread available dollars over a much greater area. Roadway deterioration can be suspended, pavements preserved and upgraded, and costly reconstruction avoided.

Note: These guideline specifications are meant for the promotion of Hot In-Place Recycling and to provide reasonable assurance to the awarding authority that quality work will be performed by the recycling contractor.

PRE-BID CONSIDERATIONS

1. Many asphalt pavements are appropriated to Hot In-Place Recycling. Pavement characteristics, relative to depth, mix design, and base stability, should be considered in the selection process.
2. Preliminary evaluation of the deteriorated pavement should be performed in the company of qualified recycling specialists to verify that the degree of distress is within the capabilities of this process for effective restoration. Localized distortions, failures, or concentration of contaminants may require advance treatment to qualify as a potential candidate.

   A request issued to interested recycling contractors listing basic data, questions, and expectations will be particularly useful, as a means for securing professional input, to agencies unfamiliar with recycling projects.
3. Surface courses containing unusually large aggregate, i.e., one-inch, may not be suitable for Hot In-Place Recycling.

4. Rejuvenation of the aged asphalt is necessary for complete recycling. For bidding purposes, a quantity factor of 0.10 gallons per square yard inch of undiluted recycling agent should be utilized. However, the awarding authority should have representative cores analyzed to determine:
   a. the penetration or viscosity of the asphalt binder,
   b. the effect on the penetration or viscosity of the asphalt binder by adding varying quantities of recycling agent,
   c. the volume of residual bitumen to reveal the practical limits for additional binding agents.

   The results of these tests should be used to select the type and quantity of asphalt recycling agent or modified new hot mix to be added to the existing material to meet the specific pavement requirements of the owner.
5. Mix design, and depth (volume) of virgin materials to be incorporated in or applied to the restored pavement remain the responsibility of the awarding authority. Specifications for final wearing course mix design can be achieved by using either the "remix" method which provides a thorough recombination of the restored existing mixture with specified virgin materials, or the single pass "repave" method, wherein the virgin materials as specified are placed on top of the restored pavement. Also, the "delay" method similarly provides for the application of specified virgin materials upon the restored pavement but, after a delay or interim period which separates the recycling and paving phases. Regional climatic conditions, raw material, availability, load bearing consideration, and service requirements shall be, as in conventional resurfacing, the basis for these considerations. Hot In-Place Recycling restores the structural integrity of the recycled pavement to the equivalent of new pavement of

similar mix design and its contribution should therefore be considered in the total pavements estimated structural capacity. Depth or volume of virgin materials specified will be affected accordingly.

GUIDELINE BID SPECIFICATIONS FOR HOT IN-PLACE RECYCLING

PREQUALIFICATION CLAUSE

Prospective bidders are hereby informed that prior to construction a complete description of the type of equipment to be used shall be supplied to the engineer. Also, a list of comparable projects performed using this equipment and the techniques specified shall be provided. In lieu of the above, the contractor may qualify his equipment by a demonstration on this or comparable work, at a speed and in a manner the same as he will conduct his operation during actual recycling operations, to the satisfaction of the engineer. The engineer reserves the right to reject equipment he feels is unsuitable. The cost of this demonstration shall be borne by the supplier.

SCOPE

Hot In-Place Recycling consists of furnishing all labor, equipment and materials and performing all operations with equipment specifically designed to heat and soften the existing asphalt concrete pavement to allow scarifying, or hot rotary mixing, to the depth specified without tensile fracturing the aggregate. The heated scarified material is then thoroughly remixed, redistributed, and leveled either in combination with, or in preparation for recycling agents and virgin materials applied as specified. All work under this item shall be in conformity with typical sections shown on the plans and to the lines and grades established by the engineer.

CLEANING AND PREPARATION

Prior to commencing hot in-place recycling operations, the pavement shall be cleaned of all loose material. Power brooms shall be supplemented when necessary by hand brooming and such other tools as required to bring the surface to a clean, suitable condition, free of all deleterious material. Localized patching, remedial conditioning, or structure adjustments should be completed prior to beginning this process.

EQUIPMENT AND CONSTRUCTION DETAILS

1. Single-Pass Method

The equipment for this type shall be self-contained, self-propelled, automated units capable of heating, viscously scarifying and/or hot rotary mixing nd redistribution with automatic screed control for longitudinal leveling of either a homogeneous mixture of existing and virgin materials to the specified depth and design (REMIXING), or a similar rehabilitation of the existing asphalt pavement upon which a totally new mix is monolithically applied in accordance with accepted bituminous paving procedures (REPAVING).

Method A: REMIX. The reclaimed materials shall be automatically fed into a mixing unit. When required, new hot bituminous pavement material and, when required, a recycling agent or other liquid additive material shall be added to the reclaimed material at the mixer. The type and quantity of the new hot bituminous pavement material and the proportion of new material and reclaimed material shall be specified in the job mix formula. All materials shall then be thoroughly mixed while maintaining the minimum temperature. After mixing, the combined bituminous materials shall be automatically fed into a finishing unit which will spread and level the mixture to the required thickness in conformance with specified cross-section, at a minimum temperature of 240°F.

Method B: REPAVE. After the addition of the recycling agent, the reclaimed material shall be gathered by a leveling device equipped with augers for mixing and spread to a uniform depth over the width being processed. After it is placed, and while it still has a residual minimum temperature of 225°F, a layer of new hot bituminous pavement material conforming to the job mix formula shall be placed over it. The application rate of the new material shall be sufficient to provide the required pavement thickness, as shown on the plans.

2. Multiple-Pass Method

The equipment for this type shall be a self-contained, self-propelled automated unit capable of heating, viscously scarifying and/or hot rotary mixing, redistributing, and screeding with a controlled leveling at crown and both extremities to insure a cross-section that conforms to the pavement profile specified. Recompaction of the restored material at a minimum temperature of 240°F follows immediately. The application of the final wearing surface follows after a prescribed interval or delay. These materials are applied with conventional equipment in conformance with standard construction techniques.

3. General (Common to all methods)

a. Heating: The equipment used to heat the existing asphalt surface shall fully meet the standards of the state and local Air Pollution control Authority. The combustion chamber shall be insulated and totally enclosed. Sufficient heat shall be generated to soften the pavement to the depth

required to achieved specified performance.

b. Scarifying: The scarifiers or rotary mixers shall be able to both thoroughly remix and recoat aggregate stripped of its bitumen coating and penetrate the pavement surface so as to cut to the specified depth, without tensile fracturing the pavement, to provide a surface conforming to the desired finished profile of the pavement.

c. Recycling Agent Applicator: The liquid spray equipment shall be capable of applying the rejuvenator in a uniform manner across the full width of the processed material and shall incorporate a meter for continuous verification of quantities. The volume applied shall vary in direct proportion to the operating speed of the recycler and shall be synchronized with the volume of material mixed or scarified to maintain a tolerance within 5 percent of the specified rate.

d. Compaction Equipment: Immediate compaction shall take place with rolling equipment of sufficient type and size to compact either virgin materials or the combined bituminous materials to the required density. State specifications for bituminous concrete surfaces shall apply. Rubber tire compaction equipment is, however, recommended for initial consolidation due to the minimum depth of the recycled or overlay materials.

PROJECT MANAGEMENT DETAILS

1. Critical Path

Sequencing of operations shall be stated by the contractor and approved by the engineer so as to cause a minimum delay in operations and to provide safety for the traveling public.

2. Verification of Depth

The weight of existing asphalt surface has been estimated to be approximately 144 pounds per cubic foot. On this basis, a minimum of 9 pounds per square foot of existing surface shall be scarified to obtain a depth of between ¾ and 1 inch. If the tests indicate that the material weighs either less than 137 or more than 151 pounds per cubic foot, the weight per square foot requirement will be adjusted accordingly by the engineer. Additional depths based on similar methods of verification may be specified.

Scarification will be deemed acceptable when the moving average of three consecutive random weight tests per hour indicates that the required depth has been obtained. The weight of the existing asphalt surface will be determined in accordance with the requirement of AASHTO T-166 from scarified material compacted in accordance with requirements of AASHTO T-245.

Wherein verification of depth by weight cannot be accomplished, such as projects using the single-pass method, effective inspection may require core analysis in combination with an accounting of virgin materials applied to verify depth of restoration.

3. Protection of Existing Improvements

Since high temperatures are required in a hot in-place recycling operation, the contractor shall exercise care against possible injury or

damage to existing improvements. Existing improvements damaged by the contractor shall be repaired or replaced to the satisfaction of the engineer at no cost to the agency.

4. Sampling

Gradation, bitumen content, density, and smoothness of the bitumen surface course materials will be sampled and tested according to recommended AASHTO guidelines.

5. Measurement and Payment

Heating, scarifying, leveling and compaction of the pavement shall be paid for at the contract unit price per square yard. Such price shall constitute full compensation for the item as herein described and specified.

Recycling agent concentrate will be paid for at the contract unit price per gallon by certified weight. The certified weight shall be determined by weighing on sealed scales regularly inspected by the State Bureau of Weights and Measures. The unit price shall include full compensation for furnishing and applying the recycling agent.

New hot mix asphalt concrete pavement material shall be measured nd paid for by the ton.

GUIDELINES FOR ASPHALT REJUVENATING AGENTS

Rejuvenating agents are hydrocarbon products that have the ability to restore aged asphalt to current standards.

PHYSICAL AND CHEMICAL GUIDELINES

On Emulsion	ASTM Test Method	Requirements Min.	Requirements Max.
Viscosity, 50°C, SSF	D-244		100
Sieve, %	D-244		0.1
Storage Stability, 24 hr, %	D-244		1.5
Residue, %[1]	D-244	65	
Cement Mixing	D-244		2.0
Specific Gravity	D-70	report	

On Residue			
Viscosity, 60°C, Cst	D-1271	75	250
Flash Point, COC, °F	D-92	375	
Saturates %	D-4124		30
Asphaltenes	D-4124		
TFOT,			
viscosity ratio	D-1754		3
weight change %	D-1754		4

[1]Residue shall be determined by evaporation method set forth in ASTM D-244, except that sample shall be maintained at 300°F until foaming ceases, then cooled and weighed.

This material has shown excellent results in the field. This is by no means the only material that may be used. Consult with your contractor and supplier for the preferred material for your Hot In-Place Recycling needs.

The above specification is not the only available or proven product for Hot In-Place Recycling. Other materials, which contain asphaltenes, may be more appropriate for certain projects or processes. Consult with your contractor or supplier for the preferred materials to suit your needs.

APPENDIX C

CALIFORNIA DOT HOT IN-PLACE RECYCLING SPECIFICATIONS

HOT-IN-PLACE RECYCLING - This work shall consist of hot-in-place (HIP) recycling the existing pavement by performing the following operations in a single pass:

1. Pre-heating the pavement using infrared heaters,
2. Hot milling the heated pavement to the required depth,
3. Remixing and blending the milled material with a recycling agent,
4. Spreading and leveling the material on the roadway,
5. Optional - Spreading and leveling a lift of new conventional asphalt concrete (AC) on top of the recycled material, and
6. Compacting the total thickness of recycled mix and, if placed, new mix in a single operation.

EQUIPMENT

The equipment as specified shall be on the project in good operating condition in sufficient time before beginning operations to allow the Engineer time to evaluate it. Any equipment which the Engineer determines to be unsuitable for the purpose intended will be rejected.

To determine the suitability of the equipment, a test strip will be required. At the beginning of the HIP recycling operations the Contractor shall construct a test strip on this project at least 0.1 mile but not more than 0.2 mile in length using the equipment and methods to be used for the remainder of the HIP recycling work on the project. No further recycling work shall be performed until the test strip is evaluated. This strip must be approved by the Engineer prior to proceeding with the work.

Pavement Pre-heaters: Pre-heaters shall be capable of heating the existing AC pavement to a temperature high enough to allow hot milling of the material to the desired depth without breaking aggregate particles, without charring the existing asphalt, and without producing undesirable pollutants. The heaters shall consist of multiple rows of infrared burners fueled by liquid propane.. Infrared is herein defined as heaters which produce heat without a visible flame. The heating mechanism shall be so equipped that heat application shall be under an enclosed or shielded hood. The equipment being used must have a combined capacity of 25,000,000 BTU per hour.

Hot Milling: The hot milling system shall be capable of uniformly loosening the existing AC pavement to the depth specified on the plans and creating a level base the full width of the pass.

Application of Recycling Agent: A metering system will be used for adding and uniformly blending a rejuvenating agent with the hot milled material. The application rate for the recycling agent shall be synchronized with the machine speed to provide application at the predetermined amount.

The equipment must be capable of heating the recycling agent up to a minimum of 200 degrees Fahrenheit before application. The recycling agent must be added prior to the area where new material may be introduced. The equipment must have an enclosed mixing chamber.

The recycling machine shall be equipped with a meter capable of registering the rate of flow and the total delivery of recycling agent introduced into the mixture. The meter shall also be equipped with valves and a nozzle, in a convenient location, for the purpose of material testing, as provided in Section 9-1.01, "Measurement of Quantities", of the Standard Specifications.

Mixer and Spreader: The equipment must have a system for uniformly mixing new AC with the recycled material. This mixing must take place in an enclosed chamber to ensure a homogeneous mixture is obtained.

Screed: A heated, vibrating screed system which is an integral part of the machine must be capable of distributing the blended mixture, without segregation, evenly over the width of the area being processed. The material must be uniformly distributed to the required profile and cross slope and must have an adjustable crown control. A second screed is required when new AC is to be added and it also must be an integral part of the machine to allow simultaneous overlaying of the recycled mixture.

Compaction: Average in-place density will be determined by nuclear gage in conformance with California Test 375. Requirements for compaction of the HIP recycled AC will be in conformance with the provisions for "asphalt concrete" found elsewhere in these special provisions.

GENERAL

Attention is directed to "Order of Work" of these special provisions.

The depth of hot milling shall be within 0.03-foot of the depth shown on the plans.

Recycling operations shall not be performed unless the atmospheric temperature is at least 50°F.

The temperature of the HIP recycled AC shall be 250°F minimum behind the screed of the recycling machine.

Cost reduction proposals to substitute AC for HIP recycled AC will not be accepted. The provisions in Section 5-1.14, "Cost Reduction Incentive," of the Standard Specifications shall not apply to recycled AC.

The amount of recycling agent to be added shall be between 0.3 percent and 1.2 percent of the dry weight of the hot milled material. The exact amount will be designated by the Engineer.

The recycling agent shall be added to the milled AC to an accuracy of plus or minus 5 percent of the amount ordered by the Engineer.

Recycling agent shall be light grade and shall conform to the specifications listed in Table 1 or a grade designated by the Engineer.

Quantities of HIP recycled asphalt concrete will be paid for by the square yard as calculated on the basis of the dimensions shown on the plans and the horizontal measurement of the actual length of pavement recycled. No allowance will be made for pavement recycled in excess of said dimensions, unless otherwise ordered by the Engineer.

Recycling agent will be measured and paid for by the ton in the same manner specified for asphalt as provided in Section 39-8.01, "Measurement," and Section 39-8.02, "Payment", of the Standard Specifications.

The contract price paid per square yard for HIP recycled AC shall include full compensation for furnishing all labor, materials (excluding recycling agent), tools, equipment, and incidentals, and for doing all the work involved in HIP recycling asphalt concrete, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

No adjustment of compensation will be made for any increase or decrease in the quantity of recycling agent required, regardless of the reason for such increase or decrease. The provisions in Section 4-1.03B, "Increased or Decreased Quantities," of the Standard Specifications shall not apply to the item of recycling agent.

TABLE 1

SPECIFICATIONS FOR RECYCLING AGENTS

TEST	TEST METHOD ASTM	TEST METHOD AASHTO	Light Grade (RA 5) min.	Light Grade (RA 5) max.
Viscosity @140°F, cSt	D2170 or 2171	T201, 202	200	800
Flash Point COC, °F	D92	T48	400	-
Saturates, Wt.%	D2007		-	30
Residue from RTF-C Oven Test @325°F	D2872	T240	-	-
Viscosity Ratio*	-	-	-	3
RTF-C Oven Weight Change, ±, %	D2872	T240	-	4
Specific Gravity	D70 or D1298	T228	Report	

$$\text{* Viscosity Ratio} = \frac{\text{RTF-C Viscosity at } 140°\text{F, cSt}}{\text{Original Viscosity at } 140°\text{F, cSt}}$$

APPENDIX D

IDAHO DOT HOT IN-PLACE RECYCLING SPECIFICATIONS

Description. Work under this item shall consist of softening asphalt pavement with heat, scarifying a minimum of the top 2 inches (0.167 ft.), and thoroughly remixing and leveling the remixed material. It shall be accomplished by a process of cleaning, heating, scarifying, applying rejuvenating agent as required, adding new hot bituminous plant mix as required, mixing, releveling, and screeding in a single pass, and recompacting the pavement surface.

Materials. Asphalt rejuvenating agent shall meet the requirements specified in the contract. New bituminous plant mix shall meet the requirements of Section 405 for the class specified in the contract.

Equipment. Heating and remixing treatment shall be accomplished using the following equipment.

(a) Processing Equipment. Heater elements shall be fueled by liquefied petroleum gas, self-propelled, and capable of processing a minimum of 1,000 square yards per hour.

The equipment train shall consist of the following in the order listed:

One or more pre-heating mechanism, consisting of clusters of radiant heaters, which radiate thermal energy to the required penetration depth without charring the asphalt and without producing unacceptable pollutants. The heating mechanism shall be equipped so heat application shall be under totally insulated enclosed hoods. Direct flame heating of the pavement surface shall not be allowed.

One or more pavement removal unit, consisting of a rotating milling

drum or acceptable scarifier, which uniformly loosens the preheated asphalt pavement to the depth specified.

A leveling system which augers material into a uniform windrow at the center of the machine ahead of the blending unit. The equipment shall have an activated, heated screed, complete with augers and strike-off device equivalent to screeds used by most asphalt pavers. Automatic grade controls shall be required.

Equipment to remix and level the windrowed material shall have a temperature controlled system to add and uniformly blend the rejuvenating agent at a predetermined rate. The application rate for the added material shall be synchronized with the machine speed to provide uniform application. The actual rate used may be adjusted, as determined by the Engineer.

A blending unit, capable of uniformly adding new bituminous plant mix at a rate of at least 75 pounds per square yard. The unit shall be capable of thoroughly mixing the material to produce a uniform mixture.

(b) Rollers. A minimum of two rollers shall be required for compacting the remixed material: One steel wheeled roller and one pneumatic-tired roller, each with a minimum weight of 12 tons, in accordance with Subsection 405.09.

Note - The Contractor is reminded that operating the heater-remix equipment must meet all requirements of Subsection 107.17 - Environmental Protection.

In the event that requirements cannot be made and the project is suspended or canceled the Contractor will bare full responsibility. No compensation will be made by the Department for costs incurred by the contractor. The Division of Environmental Quality telephone number is (208)

334-5898.

Construction. Constructing shall proceed as follows:

(a) Prior to commencing heater remixing operations, the pavement shall be cleaned of all loose material. Power brooms shall be used, supplemented when necessary, by hand brooming and such other tools necessary to clean surface, free of deleterious material. Brooming will be in accordance with Subsection 403.07.

(b) The pavement shall be evenly heated, then milled or scarified and remixed. total depth of removal shall be 2 inches minimum. Heating shall be controlled to assure uniform heat penetration without overheating, coking, or sooting of the asphalt and aggregate. When rejuvenating agent is required, it shall be applied uniformly to the mixed material prior to remixing and leveling. A metering device shall be used which automatically compensates for changes in speed of the equipment. The rate of application will be determined by the Engineer.

(c) The heating operation shall extend at least 4 inches beyond the width of remixing on both sides. When a pass is adjacent to a previously placed mat, the longitudinal seam shall extend at least 2 inches into the previously placed mat. The temperature of the milled material shall be between 200° and 300°F.

(d) Blended material shall be distributed and leveled by means of an approved paving machine with operating vibratory or oscillating screed. The machine shall screed the full width of material and shall produce a uniform cross section.

(e) The bituminous surface shall be compacted immediately after it has been distributed and leveled, in accordance with Subsection 405.16.

Acceptance Test Strip is not required.

(f) Density shall be 92 to 95 percent of maximum theoretical density, as determined by Idaho T-86. A minimum of 48 hours shall elapse before any overlay.

(g) The Contractor shall take all precautions needed to protect the adjacent landscape from heat damage. Damaged landscape shall be repaired or replaced at the Contractor's expense.

(h) The Contractor shall be required to meet all local, county, state, and federal air pollution regulations. The Contractor shall be responsible for all costs and extra work necessary to comply with air pollution regulations.

Smoothness: The finished surface shall meet requirements of Subsection 405.18 of the Standard Specifications.

Method of Measurement. The number of square yards of heating and remixing treatment will be based on the paved widths and depths shown on the plans and the horizontal measurement along centerline of the actual length of the pavement processed.

No allowance will be made for pavement processed in excess of the paved width and depth shown on the plans, unless directed by the Engineer.

Rejuvenating agent will be measured by the gallons.

Brooming will be measured by the mile and shall be one complete coverage of the entire roadway surface.

Basis of Payment. The accepted quantities of heating and remixing treatment will be paid for at the contract unit price for the following items.

Payment will be made under:

Pay Item	Pay Unit
Heating and Remixing Treatment	Square Yard
Rejuvenating Agent	Gallon
Brooming	Mile

The accepted quantities of Plant Mix Pavement Class 1 added to the treatment or placed separately will be paid for under its respective item.

The accepted quantities of Heating and Remixing Treatment shall include heating, scarifying, remixing, redistribution, releveling, and compacting the processed bituminous surfacing.

APPENDIX E

IOWA DOT HOT IN-PLACE RECYCLING SPECIFICATIONS

Section 2309. Surface Recycling By Heater Scarification

2309.01 GENERAL. This work shall consist of full-depth patching of badly deteriorated areas, surface recycling by heater scarification, resurfacing with asphalt cement concrete, and sprinkle treatment if so specified, all according to the plans and these specifications.

2309.02 SURFACE RECYCLING BY HEATER SCARIFICATION. Heater scarification and resurfacing shall be a part of a multi-step process of asphalt surface rehabilitation that consists of preparing the existing ACC surface, softening the surface with heat, scarifying the surface, and thoroughly stirring or tumbling and leveling the mixture in preparation for an asphalt surface course overlay. The work will include furnishing and placing the new surface course.

A. ***Materials*** for the surface course shall meet requirements for the type of mixture specified.

B. Equipment.

1. ***Heater-Scarifier.*** Equipment for preheating, heating, and scarifying shall be a type that has operated successfully on similar work for the Contracting Authority, or equipment proven through test results or other previous experience or both, that is satisfactory to the Engineer. Test results and other previous experience may be submitted to the Engineer, prior to the letting, for his review.

   Preheating and heater-scarification equipment shall consist of propane burners of a type specifically designed for the purpose of pavement heating and shall be capable of producing 10-36 million BTUs per hour. Heat shall be applied under an enclosure or shielded hood.

   The equipment shall meet the standards of the State Air Pollution Control laws and rules.

   Scarifying shall be accomplished with pressure-loaded rakes or scarifiers. Where scarifying to an existing curb and gutter line is required, the scarifying unit shall be equipped to scarify and move away from gutter aprons a ½-inch by 4-foot path of existing material. The scarifier shall be of a type to insure continuous and undiminished pavement contact without damaging manholes and valve boxes.

   The leveling unit shall be capable of distributing the heated and scarified material over the width being processed so as to produce a uniform cross section. The leveling device shall have the capability of windrowing excess material to one side for removal when necessary.

   The heater-scarification operation shall be capable of processing at a rate of at least 1,500 square yards per hour over a minimum one-lane width of 12 feet.

2. ***Asphalt Cement Concrete Construction Equipment.*** Equipment for batching, mixing, hauling, placing, and compacting the surface course shall meet requirements for the type of mixture specified.

C. Paving Plant Operation. Paving plant operations shall meet requirements for the type of mixture specified.

D. Construction.

1. ***Surface Preparation.*** Base repair, if required, shall meet requirements of Section 2212. Locations of full-depth patches will be designated by the Engineer.

   The pavement surface to be heater-scarified shall be prepared by cleaning of trash, debris, earth, or other deleterious substances present in sufficient quantity to interfere with the work to be performed.

2. ***Heating and Scarifying.*** The pavement surface shall be evenly heated and scarified for the full width designated on the plans as a continuously moving operation. The combination of preheater and heater-scarification units shall be such as to be able to process a minimum of 1,500 square yards per hour without charring and/or otherwise damaging the existing pavement material through exposure to heat or fire. Processing shall be at this rate except when limited by rate of delivery of the overlay mixture. The heating operation shall be controlled to prevent open flame from exiting from under the heater.

   The Engineer may require that the operation be stopped when the prevailing wind velocity exceeds approximately 10 m.p.h., and a potential hazard exists or heating and scarifying are not possible.

   The minimum depth of scarification shall be ¾-inch at the highest points, such as the edge and the high point between the wheel paths. The minimum depth of scarification shall also be ½-inch at the lowest points, such as the wheel paths. The required depth of scarification may be changed by plan notes. The scarifiers shall scarify the pavement to at least the depth specified with pressure-loaded scarifiers that plow through the pavement and loosen it without fracturing or segregating the aggregates. The surface temperature of the old pavement shall be below 475° F during heating, and the heated material shall have a temperature in a range between 220-260° F, measured immediately behind the heater-scarifier. The remixed layer shall be uniformly and evenly heated throughout. No uncontrolled heating, causing differential softening of the upper surface, shall be permitted. The heating operation shall extend at least 4 inches beyond the width of the scarification on both sides.

When a heater-scarifier pass is being made adjacent to a previously placed mat, the edge of the mat shall be luted or raked, and any damaged material shall be removed.

3. ***Leveling.*** Following the heater-scarification, the surface shall be leveled to provide a uniform cross slope. The method used to redistribute and level the scarified material shall be an approved system of augers with a strike-off plate or screed which is an integral part of the scarifying machine or an asphalt finishing machine meeting the requirements of 2001.19; this attachment or machine shall follow the scarifier as closely as practical.
4. ***Asphalt Cement Surface Course Overlay.*** After reshaping the scarified mix and before the temperature drops below 170° F, a uniform layer of new surface course material shall be placed at the rate shown on the plans. The Engineer may direct additional mixture to be added to correct irregularities. Equipment for placing and finishing the new surface shall meet requirements of 2001.19, except that a non-self-propelled finishing machine attached to the heater-scarifier may be used provided the screeding unit complies with requirements of that specification.

   When a self-propelled finishing machine is used, placement of the new surface shall be within 400 feet of the scarification operation or before the surface temperature cools to 170° F, whichever occurs first.

   Provisions shall be made for alignment and control of the scarification operation. The method used shall be subject to the approval of the Engineer.

   Aggregate for sprinkle treatment, if specified, shall be applied, as shown on the plans and as provided in 2303.12.

E. Compaction of Mixture. After the new surface course is spread, all the mixture shall be promptly and thoroughly compacted in accordance with 2303.14B.

F. Joints. Joints shall be constructed in accordance with the requirements of 2303.15 and as shown on the plans.

G. Finished Surface. Finished pavement elevations shall comply with requirements of 2303.17 and the plans. The finished cross slope shall be a plane surface with a slope as shown on the plans.

All edges, radii, and handwork shall produce a neat, finished product.

H. Safety Procedures. Prior to his operation in cities, towns or built-up areas, the Contractor shall solicit from the fire chief a recommended safety procedure to be followed and shall follow these recommendations. In addition to any other recommendations, the following procedure shall be followed:

1. Owners of underground utilities in the areas shall check the areas for possible gas leaks in or around their lines;
2. The city shall check storm sewers and sanitary sewers in the area for accumulations of sewer gas;
3. Service stations and other businesses handling flammable fuels shall be advised not to dispense same while the heater-burner is being operated within 100 feet of their business places;
4. The operation shall be planned so as to be as safe as possible for persons and properties adjacent to the work, including the traveling public. This route shall be kept open to traffic, the Contractor shall limit his operation so as to provide for this traffic, and he may be required to conduct his work during periods of light traffic.

The Contractor shall take such additional precautions as he deems are reasonable for the safety of his operation.

The Contractor shall hold the Contracting Authority and the State harmless for any damage or loss resulting from an accident, during the burning operation, caused by his failure to fulfill his obligations as outlined in these requirements.

2309.03 TRAFFIC CONTROL. Traffic control shall be in accord with the plans and 1107.09. During working hours, operations will be confined to one traffic lane except for minor encroachment on the adjacent lane to complete the work as shown on the plans. During nonworking hours, all travel lanes and shoulder shall be free of any debris or obstructions and shall be kept clear for use by traffic. At the end of the day's work, the transverse joint shall be ramped, if necessary, according to 2303.15; any surface heater-scarified but not covered by new surface course shall be leveled and compacted; and all ridges, piles, or debris shall be removed.

2309.04 LIMITATIONS. Article 2303.20 shall apply.

2309.05 MEASUREMENT AND PAYMENT. The areas satisfactorily prepared, heated, scarified, leveled, and resurfaced (new mix excluded) will be computed in square yards, and the work will be paid for at the contract price per square yard for Surface Recycling.

Asphalt Cement Concrete surface course will be measured and payment made as provided in 2303.27 and 2303.28.

Section 2310. Thin-Bonded Portland Cement Concrete Overlay

2310.01 DESCRIPTION. This work consists of a PCC resurfacing overlay of an existing PCC pavement, and it may include associated patching and widening work.

2310.02 MATERIALS. All materials shall meet the requirements for the respective items in Part IV of the Standard Specifications, with the following modifications:

A. Cement. Article 4101 shall apply. The use of Type III cement will not be permitted.

B. Aggregate. Sections 4110 and 4115 shall apply. Coarse aggregate shall be of gradation 3 or 5 and of the durability class specified for PCC pavement; however, aggregate of Class 1 durability will not be permitted.

Unless otherwise specified, the coarse aggregate shall be crushed limestone.

C. Concrete. Mix No. C-4WR, as specified in 2301.04, shall be used for resurfacing.

D. Grout for bonding new concrete to previously placed concrete shall consist of equal parts by weight of portland cement and concrete sand, mixed with sufficient water to form a stiff slurry. The consistency shall be such that it can be applied with a stiff brush or broom to the concrete in a thin, even coating that will not run or puddle in low spots. The grout shall be agitated prior to and during its use. The cement-to-water contact time of the grout shall not exceed 90 minutes before it is placed. An equivalent grout of portland cement and water, applied by pressure spray, may be substituted with approval of the Engineer.

E. Joint Filler and Sealer shall meet requirements of Section 4136.02A. For a part of this material, a white or gray filler may be required by 2310.08E.

2310.03 EQUIPMENT. Equipment used shall be subject to approval of the Engineer and shall comply with the following:

A. Surface Preparation Equipment shall be of the following types:

1. ***Sawing Equipment*** shall be capable of sawing concrete to the specified depth.
2. ***Sand-Blasting Equipment*** shall be capable of removing rust, oil, and concrete laitance from the existing surface of the pavement.
3. ***Scarifying Equipment*** shall be a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old surface to depths required in a satisfactory manner. Other types of removal devices may be used if their operation is suitable and if they can be demonstrated to the satisfaction of the Engineer.

B. Proportioning and Mixing Equipment shall meet requirements of 2001.20 and 2001.21. Sufficient mixing capacity of mixers shall be provided to permit the intended pour to be placed without interruption.

C. Placing and Finishing Equipment. An approved machine meeting requirements of 2301.07B shall be used. The machine shall be inspected and approved before work is started on each project.

The Contractor shall construct the pavement in a manner and with a system that will provide a smooth-riding surface. The placing equipment shall be either controlled to the proper elevation by stringline or operated on a pad line that is constructed to a controlled, proper elevation.

2310.04 FULL-DEPTH PCC PATCHES. Full-depth patches shall be PCC patches constructed according to the plans. Dowels will be required as shown on the plans. The patches will be full-lane width, and the minimum length of patch, measured parallel to the centerline, will be 6 feet. Full-depth patches shall be completed in an area before resurfacing work is done.

Construction of full-depth patches shall be according to Section 2215. However, joint sealing will not be required, calcium chloride shall not be used, traffic shall not be permitted on the patches for 36 hours, and smoothness will be subject to evaluation only to ¼-inch tolerance in 10 feet.

2310.05 PAVEMENT WIDENING. Pavement widening will be required at locations and as detailed on the plans.

The pavement widening shall be tied to the existing pave-

APPENDIX F

OHIO DOT HOT IN-PLACE RECYCLING SPECIFICATIONS

ITEM SPECIAL -- Asphalt Concrete Surface Recycling

<u>Description</u>. This work shall consist of in-place recycling of the existing asphalt concrete surface in a multi-step process of heating, milling, blending, spreading and compacting the recycled asphalt concrete in accordance with these specifications and in reasonably close conformity with the lines, grades and typical cross sections shown on the plans or established by the Engineer.

<u>Materials</u>. The asphalt rejuvenating agent shall be composed of a petroleum resin oil base uniformly emulsified with water. The material shall be a record of satisfactory service s an asphalt rejuvenating agent. Each shipment delivered to the project shall be accompanied by a letter of compliance by the rejuvenating agent manufacturer certifying that the material conforms to the manufacturer's current specifications, a copy of which shall be included.

Asphalt cement shall meet the requirements of 702.01 and aggregate shall meet the requirements of 703.05.

<u>Composition</u>. The Contractor shall determine the amount of new aggregate to be added to the milled material such that the gradation of the aggregates in the final recycled mixture meets the following requirements:

Sieve	Total Percent Passing
1 inch	100
½ inch	85-99
⅜ inch	70-90
No. 4	45-65
No. 8	27-50
No. 16	17-36
No. 30	12-26
No. 50	8-20
No. 100	5-14

The Contractor shall determine the amount of new asphalt cement and rejuvenating agent to be added to the final recycled mixture so that the penetration (at 77°F, 100 gram, and 5 sec) of the bituminous material in the final recycled mixture meets the range established by the Laboratory. The cost of any rejuvenating agent used shall be included in the unit bid price for asphalt concrete surface recycling.

The Contractor shall submit to the Laboratory the proposed amounts of new aggregate, new asphalt cement, and rejuvenating agent to be added to the milled material to meet the above specifications. This information shall be submitted to the Laboratory for review and approval at least 10 days prior to the commencement of work.

The new asphalt cement and aggregate shall be blended together in a bituminous concrete mixing plant in accordance with 401.

<u>Equipment</u>. Preheaters shall be a self-propelled units consisting of multiple rows of infrared burners, of a type designed to heat the upper layer of asphalt pavement. The burner assembly shall be capable of being raised or lowered by a single control and shall be adjustable in width from 11 to 14 feet. Direct or indirect open flames shall not be used. The rows of burners shall be spaced a maximum of 36 inches apart.

The recycling machine shall be self contained machine capable of recycling asphalt concrete pavements in place. It shall have the following integral components:

1. Additional heaters conforming to the above requirements for

preheaters.

2. A rotating milling drum which is capable of uniformly loosening the asphalt pavement to the depth specified in the plans. This milling unit shall be capable of making separate automatic height adjustments in order to clear obstructions and shall be adjustable in width from 11 to 14 feet. All milled material shall be windrowed.

3. A spraying system which can uniformly spray the rejuvenating agent, at a specified rate, on the milled material before it enters the blending unit.

4. A blending unit with a twin-shafted pugmill capable of uniformly mixing the specified amount of new asphalt cement and aggregate with the milled material.

5. A heated oscillating screed capable of uniformly spreading the blended materials to the required cross section and profile.

Compaction Equipment shall be rollers meeting the requirements of 401.11.

Field Laboratory. The Contractor shall have a field laboratory to provide for testing of the existing asphalt concrete pavement and final recycled mixture. These test results are to be utilized in making adjustments to the amount of new aggregate, new asphalt cement, and rejuvenating agent to be added to the milled material to meet the above specifications.

Weather Limitations. This work shall be performed only when the weather is dry and there is no free water on the pavement. The atmospheric temperature shall be over 40°F for courses of 1.5 inches or greater and over

50°F for courses under 1.5 inches.

Preparation of Existing Surface. Prior to surface recycling, the existing surface shall be cleaned in accordance with 407.04. All cracks in the existing pavement shall be cleaned of all foreign material with high pressure air cleaning equipment capable of delivering not less than of 150 psi air pressure at the nozzle into the crack being cleaned. All potholes and large depressions in the existing surface shall be filled with 402 or 404. The location of utility structures shall be marked alongside the work when the milling unit is manually controlled.

Construction Procedures. The existing asphalt concrete pavement shall be evenly heated to a temperature of between 225 and 260°F and milled to the width and depth shown on the plans. Then, any new aggregate, new asphalt cement, and rejuvenating agent shall be added to the milled material in the amount approved by the Laboratory. The milled material, new aggregate, new asphalt cement, and rejuvenating agent shall be uniformly mixed. The heated oscillating screed shall then spread the blended materials to the specified cross-section and profile in an acceptable, finished condition ready for compaction.

The Contractor shall prime the recycling machine at the beginning of each day's operation with asphalt concrete. This asphalt concrete shall meet the requirements of 448 Type 1 and shall be included in the unit bid price for asphalt concrete surface recycling.

The recycled asphalt concrete shall be immediately compacted in accordance with 401.14. The finished surface shall meet the requirements of 404.16.

Any damage of trees, shrubs or other adjacent property; or danger to the traveling public; shall be immediate cause for the Contractor to cease operations until proper adjustments are made.

Method of Measurement. Asphalt concrete surface recycling shall be measured by the number of square yards of pavement surface recycled in accordance with the plans and this specification.

The asphalt cement and aggregate blend shall be measured by the number of tons in accordance with 109.01.

Basis of Payment. The accepted quantities of asphalt concrete surface recycling complete in place will be paid for at the contract price for:

Item	Unit	Description
Special	Square Yard	Asphalt concrete surface recycling
Special	Ton	Asphalt cement and aggregate blend

APPENDIX G

TEXAS DOT ASPHALTIC CONCRETE SURFACE REHABILITATION

358.1. **Description**. This Item shall govern for asphaltic concrete surface rehabilitation, a process that consists of softening the existing asphaltic concrete surface with heat, scarifying to the depth shown on the plans, and thoroughly remixing, leveling and compacting the material. Scarified material shall be blended with fresh hot asphaltic concrete mixture, and when required, with an asphalt recycling agent.

358.2. **Materials**. All materials shall conform to the pertinent requirements of the following Items:

Item 300, "Asphalt, Oils and Emulsions"
Item 340, "Hot Mix Asphaltic Concrete Pavement"

The fresh hot mix asphaltic concrete mixture shall meet the requirements shown on the plans or as directed by the Engineer. The materials used to produce the fresh hot mix asphaltic mixture shall meet the requirements of Article 340.2.

358.2. **Equipment**.

(1) **Processing Equipment**. The equipment for heating, scarifying, mixing, placing and finishing shall be as approved by the Engineer. The equipment shall consist of the following:

(a) A heating mechanism capable of heating the asphaltic concrete pavement to a temperature high enough to allow scarification of the material to the desired depth without breaking aggregate particles, without charring the existing asphalt, and without producing undesirable pollutants. The heating mechanism shall be so equipped that heat application shall be under an enclosed or shielded hood.

(b) Scarifier sections capable of uniformly loosening the asphaltic concrete pavement to the depth specified and, when shown on the plans, equipped with separate automatic height adjustments in order to clear utility manholes and other obstructions in the pavement surface.

(c) A system for adding and uniformly blending an asphalt recycling agent during the mixing operation. The system shall be synchronized to provide a uniform application at the specified rate.

(d) A unit capable of gathering the heated and scarified asphaltic concrete pavement, adding and uniformly mixing fresh asphaltic concrete, and distributing the blended mixture over the width being processed.

(e) A spreading and finishing system capable of producing a smooth surface which meets the requirements of the typical cross section.

(f) An onboard pugmill, if required on the plans.

(2) **Rollers**. Rollers shall be in accordance with Subarticle 340.4(6).

(3) **Mobile Testing Laboratory**. When shown on the plans, a mobile testing laboratory and a laboratory technician shall be furnished by the Contractor. These shall meeting the requirements shown on the plans.

358.4. **Construction Methods**.

(1) **General**. The pavement surface to be rehabilitated shall be cleaned of all dirt and other objectionable material by blading, brooming or other approved methods, prior to beginning heater-scarification operations.

(2) **Heating, Scarifying and Placing**. The pavement surface shall be evenly heated, scarified and reworked to the widths and depths shown on the plans. Heating shall be controlled to assure uniform heat penetration without causing differential softening of the pavement. Charring of the asphalt will not be permitted. The scarified material shall be gathered mixed and laid. The asphalt recycling agent, when required, shall be applied uniformly to the scarified material prior to mixing and leveling unless otherwise approved by the Engineer. The rate of application shall be as selected by the Engineer based on laboratory tests on pavement samples. The required amount fresh hot mix asphaltic concrete shall be added and thoroughly mixed with the scarified material, and the blend shall be leveled, and compacted.

All work under this Item shall be in conformity with the typical sections shown on the plans and to the lines and grades as established by the Engineer.

The heated and scarified material shall have a temperature between 225°F and 265°F as measured immediately behind the scarifier.

There shall be no burning of trees, shrubs, or other landscaping adjacent to the pavement. It shall be the responsibility of the Contractor to protect the adjacent landscape from heat damage.

When a pass is made adjacent to a previously placed mat, the longitudinal joint shall extend at least 2 inches horizontally into the previously placed mat, unless otherwise directed by the Engineer.

(3) **Compaction**. Compaction shall begin before the material temperature drops below 190°F. All rolling shall be completed before the mixture temperature drops below 175°F unless determined by the Engineer that a higher minimum temperature is required for proper compaction.

Rolling shall be continued until no further compaction can be obtained and all roller marks are eliminated. One (1) tandem roller, one (1) pneumatic-tire roller and at least one (1) three-wheel roller, shall be provided for each work site unless otherwise directed by the Engineer.

The Contractor may, with permission from the Engineer, operate other compacting equipment that will produce equivalent compaction as the specified equipment. If the substituted compaction equipment fails to produce the compaction expected of the specified equipment, as determined by the Engineer, it use shall be discontinued.

The edges of the pavement along curbs, headers and similar structures, and all places not accessible to the roller, or in such locations as will not allow thorough compaction with the rollers, shall be thoroughly compacted with lightly-oiled tamps.

358.5. **Measurement**. Asphaltic concrete surface rehabilitation will be measured by the square yard of surface area of completed and accepted work of the depth shown on the plans. Asphalt recycling agent will be measured by the gallon. The fresh hot mix asphaltic concrete shall be measured in accordance with Item 340, "Hot Mix Asphaltic Concrete Pavement".

358.6. **Payment**. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for as follows:

(1) **Asphaltic Concrete Surface Rehabilitation**. Asphaltic concrete surface rehabilitation will be paid for at the unit price bid for "Asphaltic Concrete Surface Rehabilitation". This price shall be full compensation for cleaning existing pavement, all heating, scarifying, mixing, relaying, rolling, finishing, and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

(2) **Asphalt Recycling Agent**. Recycling agent will be paid for at the unit price bid for "Recycling Agent". This price shall be full compensation for furnishing, hauling, applying and mixing the material; and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

(3) **Fresh Hot Mix Asphaltic Concrete**. All fresh hot mix asphaltic concrete shall be paid for in accordance with Item 340, "Hot Mix Asphaltic Concrete Pavement."

APPENDIX H

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT SPECIAL PROVISION FOR ASPHALT CONCRETE SURFACE REHABILITATION

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 20120

ALTERNATE NO. 3

ASPHALT CONCRETE SURFACE REHABILITATION

DESCRIPTION. This item shall consist of rehabilitation of the existing asphalt concrete surface in a simultaneous, multi-step process of heating, scarifying, thoroughly remixing to the depth shown in the plans and reshaping the old asphaltic surface, adding rejuvenating agent and then placing an overlay of new asphalt concrete pavement in conformity with the lines and grades shown on the plans or as designated by the Engineer.

Asphalt concrete hot mix wearing surface shall be in accordance with Section 406 or 413 as specified of the Standard Specifications for Highway Construction, edition of 1988.

MATERIALS. Asphalt rejuvenating agent (if required) shall meet the following requirements:

Property	Test Method	Requirements Min.	Max.
Viscosity at 77°F, (SF)	AHTD Test 411	15	100
Sieve Test, (%)	AASHTO-T59	--	0.10
Residue, (%)	AASHTO-T59	60	--
Asphaltenes, (%)	ASTM D2006		1.0
Residue Tests (From Evaporation)			
Viscosity at 140°F, (cSt)	AHTD Test 415	75	250
Flash Point, (°F)	AHTD Test 403	375	--

MIX DESIGN. The Department shall determine, prior to construction, the asphalt content of the existing material to be scarified, the penetration of the asphalt cement in the existing material, and the amount of rejuvinator needed. The mix design will also state the expected void level of the recompacted and rejuvenated pavement as well as a target penetration value.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 20120

ALTERNATE NO. 3

ASPHALT CONCRETE SURFACE REHABILITATION

QUALITY CONTROL. The contractor shall produce a recycled asphalt course that is not over asphalted or composed of asphalt of insufficient quality. The recycled mixture shall be tested by the contractor during the first days production to verify the mix design. The contractor shall perform the following tests for mix verification.

(1) Determination of Asphalt Content of Bituminous Mixture (AHTD Test 450 or 451 or other approved method).

(2) Determination of maximum specific gravity of recycled course (AASHTO T209).

(3) Recovery of Asphalt from solution by Abson method for recycled course (AHTD Test Method 422).

(4) Penetration of Bituminous Materials from recycled course (AHTD Test Method 404).

In addition, Density samples of the recycled lift will be taken at the same rate and requency as required for the virgin asphalt concrete overlay.

The work involved in providing quality control will not be paid for directly but will be considered included in the price bid for Asphalt Concrete Surface Rehabilitation.

EQUIPMENT

(a) Processing Equipment. The equipment shall consist of a single self-contained machine specifically designed to re-process upper layers of existing asphalt pavements. This machine shall be as approved by the Engineer. The heater-scarifier-repaver unit shall consist of at least the following:

(1) A heating mechanism capable of heating the asphalt concrete pavement surface to a temperature high enough to allow full depth of required scarification of the material without breaking aggregate particles, without charring the pavement, and without producing undesirable pollutants. The heating mechanism shall be so equipped that heat application shall be under an enclosed or shielded hood to prevent damage to outlying grass, shrubs, or trees. In the event of burning of the asphalt or excessive production of pollutants, the Engineer may require that operations be discontinued. Operations may not be resumed until adjustments have been made to the satisfaction of the Engineer.

(2) Scarifying sections shall be equipped with separate automatic height adjustments in order to clear utility manholes and/or other obstructions in the pavement surface. These sections shall be able to penetrate the surface a minimum of 1 inch. The machine must have sufficient power to push the scarifiers through the high spots and create a leveled surface conforming to the desired finished profile of the pavement.

(3) A leveling unit capable of gathering the heated and scarified material into a windrow or otherwise leveling the material in a manner acceptable to the Engineer, and then distributing the material over the width being processed so as to produce a uniform cross section.

(4) A system for adding and blending rejuvenating agent at the rate determined by the mix design. The application rate will be synchronized with the machine speed to provde uniform application and maintain a tolerance of less than 5% from the rate determined in the mix design.

(5) A spreading and finishing mechanism capable of producing a surface that will meet the requirements of the typical cross section and surface tests, when required. Automatic screed control, if required, shall meet the requirements of the AHTD for Automatic Screed Controls for Asphaltic Concrete Spreading and Finishing Machines, 1988.

(b) Rollers. Rollers shall be in accordance with Section 409 of the Standard Specifications.

CONSTRUCTION METHODS

(a) General. The pavement surface to be rehabilitated shall be cleaned of all dirt and other objectionable material by blading, brooming or other approved methods, prior to beginning heating and scarifying operations. It shall be the responsibility of the Contractor to protect the adjacent landscape from heat damage. This protection may consist of individual shielding and/or water spray or other methods approved by the Engineer. The work under this specification will not be allowed unless the air temperature is 50°F and rising.

(b) Heating, Scarifying and Rejuvenating. The pavement surface shall be evenly heated, scarified and re-worked to the widths and depths shown on the plans. Heating shall be controlled to assure uniform heat penetration

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 20120

ALTERNATE NO. 3

ASPHALT CONCRETE SURFACE REHABILITATION

without causing differential softening of the surface. Charring of the asphalt will not be permitted. The scarified material shall be gathered by the leveling device, and spread uniformly to a minimum depth of 3/4 inch. Under no circumstances shall the scarifying penetrate into the existing aggregate base course.

The heated material shall have a temperature in a range between 225°F and 265°F as measured immediately behind the scarifier. The Engineer will determine the temperature within these limitations, and the mixture shall not vary from this selected temperature more than 25°F.

Rejuvenating agent, if required, shall be applied uniformly to the scarified material prior to leveling and mixing, or as directed by the Engineer. The rate of application shall be as determined by the Engineer based on laboratory tests on pavement samples.

(c) Overlay. New asphalt concrete surface overlay shall be placed over the leveled, rejuvenated pavement. The new overlay shall be placed and spread using a vibratory screed, which shall have an automatic longitudinal screed control. The machine that performs the recycling shall be the same machine that places the new overlay wearing course.

When a pass is made adjacent to a previously place mat, the longitudinal joint shall extend at least two inches horizontally into the peviously placed mat.

(d) Compaction. Rolling and compaction will begin immediately behind the spreader and shall be in accordance with Section 410 of the Standard Specifications.

METHOD OF MEASUREMENT. Asphalt Concrete Surface Rehabilitation will be measured by the square yard. Rejuvenating agent will be measured by the gallon. Asphalt concrete hot mix wearing course shall be measured in accordance with Section 406 or 413 as specified.

BASIS OF PAYMENT. Work completed and accepted and measured as described above will be paid for as follows:

(a) Asphalt Concrete Surface Rehabilitation shall be paid for at the unit price bid per square yard for "Asphalt Concrete Surface Rehabilitation", which price shall be full compensation for cleaning existing pavement; for all heating and scarifying, mixing and relaying or scarified materials; and for all labor, tools, equipment and incidentals necessary to complete the work.

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

SPECIAL PROVISION

JOB 20120

ALTERNATE NO. 3

ASPHALT CONCRETE SURFACE REHABILITATION

(b) Asphalt concrete hot mix wearing course shall be paid for in accordance with Section 406 or 413. The unit price for this item shall be full compensation for furnishing and hauling the asphalt concrete hot mix wearing course and for all manifestations, labor, tools, equipment and incidentals necessary to complete the work.

(c) Rejuvenating agent used shall be paid for in accordance with the Item "Rejuvenating Agent". The unit price bid for this item shall be full compensation for furnishing, transporting, and properly mixing the rejuvenating agent in the recycling process; and for all labor, tools, equipment and incidentals necessary to complete the work.

Payment will be made under:

Pay Item	Pay Unit
Asphalt Concrete Surface Rehabilitation	Square Yard
Asphalt Concrete Hot Mix Surface Course	Ton
Asphalt Concrete Hot Mix Seal Course	Ton
Rejuvenating Agent	Gallon

TE 7 .N26 no. 193 ---31225

Button, Joe W.

Hot in-place recy... E
asphalt ...

DATE DUE

---31225

ConnDOT Library & Information Center
2800 Berlin Turnpike
Newington, CT 06111-4116

DEMCO

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

MTA DOROTHY GRAY LIBRARY & ARCHIVE
100000308401