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EXTENSION AND REPLACEMENT OF ASPHALT CEMENT WITH SULFUR

Executive Summary

October 1978

Final Report

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D.C. 20590

FOREWORD

This Executive Summary should be of interest to research and operations personnel concerned with the design, construction, and evaluation of pavements using sulfur extended asphalt binders.

It concisely summarizes and presents the major conclusions of a comprehensive research report concerning the use of elemental sulfur to partially replace asphalt in bituminous paving mixtures. For a more detailed and complete account of the material in this summary, the reader is referred to report no. FHWA-RD-78-95, "Extension and Replacement of Asphalt Cement with Sulfur."

This report is being distributed in sufficient numbers to provide a minimum of one copy to each regional and division office, and two copies to each State highway agency. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5385 Port Royal Road, Springfield, Virginia 22161.

Charles F. Scheffey
Director, Office of Research

NOTICE

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16. Abstract

The potential shortage of asphalt cement and oversupply of sulfur make it advantageous to reduce the dependence of the paving industry upon asphalt cement while utilizing readily available sulfur. This report presents the results of an investigation of the use of elemental sulfur as a partial replacement and/or extender of asphalt cement in highway paving mixtures.

Physical properties of numerous combinations of sulfur-asphalt emulsions were determined. Various aggregates, asphalt cements, and sulfur were tested in a series of laboratory screening tests utilizing nine independent design variables. Characterization tests were performed on selected combinations of aggregate, asphalt and sulfur utilizing three different mixing methods.

The resulting relationships between response characteristics, mixture compositions, and design variables were programmed into the Texas FPS-BISTRO and VESYS IIM design programs. Texas FPS-BISTRO screened a number of design combinations to find the optimum combinations. VESYS IIM was used to evaluate performance of selected optimum pavements.

The studies indicate that the addition of sulfur to asphaltic concrete can produce pavements which are more economical with performance characteristics equal or superior to conventional asphaltic concrete pavements.

17. Key Words
sulfur, asphalt, emulsions, aggregates characterization, Texas FPS-BISTRO, VESYS IIM, fatigue, rutting, service-ability index, slope variance, mix design, performance prediction, pavement systems design.

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PROLOGUE

The purpose of this document is to summarize and present the major conclusions of a comprehensive research report published by the Federal Highway Administration. The report, dealing with the use of elemental sulphur to partially replace asphalt cement in bituminous paving mixtures, has been published as report no. FHWA-RD-78-95, "Extension and Replacement of Asphalt Cement with Sulfur."

BACKGROUND

Asphalt is an extremely important highway construction material. Asphalt type materials have been used to construct more than 90 percent of the total hard-surfaced road system of the United States. About 22.7 million metric tons of asphalt are used annually in construction of new roadways, whereas about 6.4 million metric tons are used for maintenance and rehabilitation of the existing road system.

Asphalt is obtained by refining crude petroleum. As the current energy shortage has developed, it has increasingly become more profitable for refiners to use the asphalt residue in blending of heavy fuel oil rather than marketing the asphalt as an individual product. This fact has caused a reduction in the amount of asphalt materials available for roadway construction with a resultant increase in the price of asphalt during the last few years. Bid prices for asphalt cement have tripled in some regions of the country during the last four years.

With the apparent shortage of asphalt materials, researchers, material suppliers, design engineers, and the construction industry are exploring ways to use available materials, such as local aggregates, waste materials, and substitute binders, more efficiently for roadway construction. It is highly desirable that a substitute or supplement for asphalt cement be developed. Elemental sulphur has played a major role in this search for methods to reduce the dependence of our nation upon the use of asphalt cement as a highway paving material. Existing world stockpiles of sulphur are estimated to be 26 million metric tons due primarily to pollution abatement processes which are recovering sulphur from various sources. Sulphur is one of few commodities which is expected to be in surplus in the future. In 1975, world production of sulphur totaled 52 million metric tons while consumption amounted to 45.7 million metric tons. The oversupply of sulphur has kept its commercial price low. The combination of the shortage of asphalt cement and the overabundance of sulphur has set the stage for researching the practicality of substituting the latter product for the former.

Utilization of recovered sulphur as a substitute or supplement for asphalt cement would serve a twofold purpose: an outlet would be provided for the current oversupply of sulphur, and the dependence of the paving industry upon the use of asphalt cement would be reduced. Another potential benefit is the possibility of improved performance of pavements incorporating sulphur as an extender of the asphalt cement binder.

OBJECTIVES

The general purpose of this study was to investigate the use of elemental sulphur as a partial replacement and/or extender of asphalt cement in highway paving mixtures. The specific major objectives of this study are as follows:

1. To investigate the effect of the addition of elemental sulphur on the physical properties of sulphur-asphalt emulsions.
2. To investigate the solubility and settling characteristics of sulphur in various asphalt cements.
3. To develop statistically based relationships between mixture response characteristics and mixture composition and design variables.
4. To evaluate and demonstrate the influence of partial substitution of sulphur for asphalt cement in asphalt paving mixtures.
5. To determine suitable mix design alternatives which will result in a reduction of the quantities of apshalt cement normally specified, but which will still yield a comparable level of performance as provided by conventional asphalt mixtures in flexible pavements.
6. To make comparative analyses of pavement systems utilizing conventional asphaltic concrete and sulphur-asphalt concrete.

RESEARCH APPROACH

The purpose and objectives of this study were accomplished by means of five major tasks listed below.

Task A - Selection of Design Systems and Materials Characterization Tests
Task B - Development of Sulphur Extended Asphalt Systems.
Task C - Development of Statistically Based Relationships from Laboratory Tests for Use in Pavement Design Systems.
Task D - Incorporate Statistical Relationships into Pavement Design Systems.
Task E - Sensitivity Analyses.

Study of the available literature indicates that two different methods have been used by researchers to introduce sulphur into the paving mixture. In order to determine the differences and advantages of the systems, three alternative approaches were investigated for this project. These three systems are a) Aggregate-Asphalt-Sulphur (AAS), b) Aggregate-Emulsion (AE), and c) Aggregate-Emulsion-Sulphur (AES). The letters designate the order in which the components are added to the mixture. In the AAS system, the aggregate is first mixed with the liquid asphalt cement and then the molten sulphur is added. In the AE system, the sulphur and asphalt cement are first mixed to form an emulsion which is then mixed with the aggregate. In the AES system, a sulphur-asphalt emulsion is mixed with the aggregate and molten sulphur is then mixed with this combination.

Task A consisted of a literature review, selection of the pavement design system and structural design subsystem to be used in application of the test results and analysis thereof, and determination of the characterization tests necessary for input data to the selected design system and subsystem.

Task B consisted of selection of the experimental design variables and mixture combinations, and determination of the physical properties of sulphur-asphalt emulsions (SAE) using various grades of asphalt cements and quantities of sulphur. An experimental design was developed in order to determine what combinations of variables should be tested in order to examine the relative influence of various factors and their first order interactions on the behavior of the compacted mixture combinations. In addition, numerous combinations of aggregate, asphalt and sulphur were prepared using the three sulphur-asphalt systems for subsequent testing. Laboratory tests were performed on the SAE binders to determine the specific gravity, ring and ball softening point, viscosity, penetration, sulphur settling rate, and amount of dissolved sulphur for each combination of sulphur and apshalt.

Task C included an extensive laboratory testing program from which statistically-based relationships between mixtures, design variables and response characteristics were developed for subsequent incorporation into the selected pavement structural design subsystem. A series of preliminary screening tests in this task included determination of unit weight, percent air voids, percent voids in mineral aggregate, Marshall stability and flow, and Hveem stability. Based upon results of the screening tests, the dominant variables were determined. Further qualification tests included resilient modulus, flexure fatigue properties, thermal expansion, creep properties, and permanent deformation properties. The screening and qualification test data were analyzed, and the relationships and parameters necessary for evaluation of pavement systems were developed.

Task D required programming of the developed statistical relations into the selected structural design subsystem and pavement design system. Specific distress mechanisms treated within the subsystems included fatigue cracking, rutting, and roughness.

Task E was used to find optimum combinations of material properties and layer thicknesses which will be cost effective in different climates, on different subgrades and base courses, and under different loading conditions. A selected pavement design system (FPS-BISTRO) was used to screen a large number of possible design combinations to determine the most effective designs for cold, moderate and warm climates. Using a structural design subsystem (VESYS IIM), the optimum pavements were studied to determine their resistance to various forms of distress.

CONCLUSIONS

Based upon analysis of the experimental data, observations, and other information gained from this research program the following conclusions are made:

1. When mixed with asphalt cement to form an emulsion, sulphur alters the physical properties of the asphalt cement. These properties, as determined by standard laboratory tests, are dependent upon the amount of sulphur added. As determined experimentally for this project, the general trend of the physical properties follows:

    a. The specific gravity of the emulsion increased with sulphur content.

    b. The penetration increased with sulphur content up to about 20 to 30 w/o*sulphur, and then decreased as the sulphur content continued to increase.

    c. The ring and ball softening point increased slightly with sulphur content.

    d. Viscosities decrease with increasing sulphur content up to about 20 to 30 w/o sulphur, and then increase rapidly with further increase of sulphur content.

2. As the viscosity of the asphalt cement increased, the amount of sulphur which settled from the sulphur-asphalt emulsion decreased. Very little sulphur settled from emulsions containing 20 weight percent or less sulphur.

3. The amount of sulphur which can be dissolved by asphalt cement depends upon the mixing temperature and grade and source of the asphalt cement.

4. Paving mixtures containing sulphur must be compacted at temperatures in excess of the solidification point of sulphur, or the structuring effect will be destroyed.

5. A sensitivity analysis indicated that the resilient modulus and Marshall stability are more sensitive to aggregate properties for the AAS system, whereas the two test variables are more sensitive to the degree of compaction for the AE and AES systems.

6. For paving mixtures with approximately constant total binder (sulphur and asphalt cement) content, the bulk specific gravity, Hveem and Marshall stabilities, and resilient moduli increase with increasing sulphur content.

7. The fatigue and permanent deformation characteristics of paving mixtures containing sulphur were determined. The value of K_1 decreases whereas the value of K_2 increases as sulphur content increases. The time-temperature parameter BETA decreases with increasing sulphur content up to about 20 w/o of the binder where it increases along with sulphur content.

*w/o = weight percent

9. The Texas FPS-BISTRO program for pavement system design was used to find optimum combinations of material properties and layer thicknesses which would be least expensive in various climates. Based upon the conditions, constraints, and material properties used in the study, the total cost for a pavement structure increases as the temperature increases. Within a given temperature category, a design with sulphur-asphalt concrete is the most economical. For temperatures of 40 and 72^{o}F (4 and 22^{o}C), a design containing the sand-asphalt-sulphur base courses proved to be most economical whereas a design with the crushed limestone base course results in the most effective pavement at a temperature of 120 F^{o}(49^{o}C).

10. The VESYS IIM structural design program was used to evaluate the structural integrity of the optimum pavement designs as determined from the FPS-BISTRO analysis. The following can be concluded from the VESYS IIM study:

    a. Based on predicted rut depth, roughness (slope variance), cracking, and present serviceability index, sulphur-asphaltic concrete (AAS) and the sulphur recycled optimum pavements performed as well or better than the optimum conventional asphaltic concrete.

    b. Based on the same criteria, the optimum pavements with a sand-asphalt-sulphur base had poorer predicted performance than the optimum pavements with a limestone base.

11. The results of the screening tests indicate no significant difference in the properties of the paving mixtures containing sulphur prepared by the AAS, AE, and AES systems. In view of the observed differences in pavement performance as predicted by FPS-BISTRO and VESYS IIM, it is apparent that the simple screening tests (stability, flow, strength, and resilient modulus) will not be good indicators of the field performances of these mixtures.

12. On the basis of the VESYS II predictions, it appears that there is no advantage to the use of a sulphur-asphalt emulsion prepared in a colloid mill rather than direct introduction of sulphur and asphalt cement into the mixture.

13. Laboratory and theoretical studies indicate that the addition of sulphur to asphaltic pavements can produce better, more economical pavements.

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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