STRENGTH AND RUTTING CHARACTERISTICS OF ASPHALT PAVEMENTS IN MANITOBA

by

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A Thesis

Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for the Degree of

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Abstract

This research investigates the strength and rutting performance of in-service asphalt pavements in Manitoba using a simple, modified version of the static indirect tensile (IDT) strength test. The aim of the research is to evaluate the strength and deformation properties of asphalt mixtures and relate these fundamental properties to observed rutting behaviour in the field. This represents a significant shift from traditional mix evaluation methods, which rely primarily on mix volumetric properties and empirically based tests, such as Marshall stability and flow, to assess rutting resistance. Experience gained in this area will serve to help in the selection of suitable mix designs that are more resistant to rutting.

Cored samples were collected from ten representative highway sections across the province with varying age, traffic, and rut depth characteristics. Twenty-one cores were obtained from each pavement section: three from both the inner and outer wheel paths and 15 from the area between wheel paths. The cores were obtained from three randomly selected areas within each pavement section. Mix volumetrics and binder properties were determined from 12 of the core samples while three samples per site were tested for strength and performance parameters. Performance of the samples was determined using a modified form of the static indirect tensile strength test at 25°C. The specimens were loaded diametrally at a loading rate of 0.1 mm/minute until failure occurred. Miniature LVDTs mounted directly on the central portion of the sample measured the lateral and axial deformations while a load cell captured the strength data continuously throughout testing.

Simple regression analysis was employed to relate the rutting data from each pavement section to mix volumetric properties obtained in the laboratory and to the strength parameters measured during IDT testing. Analysis of the test results showed poor correlation between mix

volumetric properties and rutting performance. The measured lateral to axial deformation ratio and Poisson's ratio at both 10 and 25 percent of the failure load, however, were found to be highly proportional to rutting. Test results showed that the test is consistent, particularly up to 25 percent of the peak load, and as such, shows promise as a means to evaluate mixture strength in relation to rutting.

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Nomenclature

Keywords

Asphalt Binder

Asphalt Concrete

ESAL

Permanent Deformation

Plastic Flow

Poisson's Ratio

Rutting

Stability

Strength

Abbreviations

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ESAL	Equivalent Single Axle Load
IDT	Indirect Tensile
LTPP	Long-Term Pavement Performance
LVDT	Linear Variable Differential Transducer
MTGS	Manitoba Transportation and Government Services
PG	Performance Grade
PTH	Provincial Trunk Highway
RAP	Reclaimed Asphalt Pavement

RTAC	Roads and Transportation Association of Canada
Superpave	Superior Performing Asphalt Pavements
SHRP	Strategic Highway Research Program
TEF	Truck Equivalency Factor
VFA	Voids Filled with Asphalt
VMA	Voids in the Mineral Aggregate

Chapter 1

INTRODUCTION

1.1 The Research Need

One of the most significant challenges facing highway departments today is the mitigation of, or at least the minimization of, permanent deformation in asphalt concrete (AC) pavements. Permanent deformation, commonly referred to as rutting, manifests itself as longitudinal depressions in the wheel paths called ruts. Rutting is initiated by heavy traffic loading, which if sufficiently large, will cause one or more of the pavement layers to experience unrecoverable deformation. Over time these small permanent deformations accumulate to form ruts, thereby reducing driver safety and overall driving comfort and eventually forcing rehabilitation of the pavement section. As a result, highway agencies across the country spend millions of dollars each year to address the rutting problem.

The rutting problem is certainly not new to pavement engineers. In fact, rutting in asphalt pavements has been a problem since asphalt was first introduced as a paving material. Research and technological advancement have improved our understanding of rutting and provided new tools and methodologies to address the problem, but because of rapid change in the transportation industry, the problem remains. Today, highway pavements are being subjected to higher load levels than ever before due to increased truck traffic, higher tire pressures, and greater axle weights. Continued advancement in transport technology, coupled with industry demands for changed trucking legislation, will likely lead to even higher allowable pavement loadings in the future. Moreover, these changes are being experienced at a time when highway maintenance budgets are generally on the decline. As a result, it is becoming increasingly difficult for highway agencies to maintain the condition of their pavement infrastructure and to provide safe, smooth highways that are resistant to rutting.

1.1.1 Review of Asphalt Mix Design in Relation to the Rutting Problem

The manner in which asphalt pavements are designed has changed considerably over the last century. One of the primary reasons asphalt mix design procedures have changed has been to address the rutting problem. The following section describes the historical development of asphalt mix design and the measures taken to evaluate rutting susceptibility in the laboratory. Invariably, each design method determines rutting susceptibility by relating some measure of mixture stability (strength) to field experience.

The first scientific approach to asphalt mix design was developed by P. Hubbard and F.C. Field in the early 1900s. The Hubbard-Field method, as it was known, was based on the determination of asphalt content from aggregate gradation (Asphalt Institute, 1996). Mixture stability was measured using a punching-shear failure test. In this test, a 102 mm (4 inch) diameter sample is compacted by means of a drop-hammer, heated to 60°C, and placed in a cylindrical mould with unequal top and bottom openings. A vertical load is applied at a rate of 51 mm/minute and the maximum load required to force the mixture through is recorded as the mixture stability.

Roughly 30 years later, the Hveem method was developed by Francis Hveem of the California Department of Transportation. In this system, 102 mm (4 inch) diameter specimens are prepared using kneading compaction to simulate field compaction. Mixture stability is measured using the Hveem Stabilometer, a device that is similar to a standard triaxial cell. The test applies a vertical load to the specimen and measures the amount of horizontal pressure that develops in the surrounding fluid. This provides a measure of the mixture's resistance to lateral deformation under vertical loading. The load is applied at a rate of 1.27 mm/min and a temperature of 60°C. Standard mix design procedures are found in ASTM D 1560 and D 1561.

In the 1940s, Bruce Marshall of the Mississippi State Highway Department developed the Marshall method, which is still used by many agencies today, including Manitoba Transportation and Government Services (MTGS). The Marshall method was later refined by the U.S. Army Corps of Engineers to address the rutting problems of military airfield pavements during World War II (Huber, 1999). Stability, density, and voids analyses form the basis of this mix design method. Impact compaction is utilized to prepare laboratory samples for determination of density and optimum volumetric properties such as asphalt content, air voids, and voids filled with asphalt (VFA). Resistance to rutting is estimated by the Marshall stability test, which measures the maximum load and flow experienced by a 102 mm diameter sample subjected to a vertical load applied along its diametral axis. The rate of loading is 51 mm/min (2 inches/min) and the test temperature is 60°C. Extensive field experience has shown that mixtures with higher Marshall stabilities generally have higher rutting resistance. This method, except for changes in specification values, has remained virtually unchanged since its development (Kandhal, 1990). Standard Marshall mix design procedures are found in ASTM D 1559.

In 1987, the Strategic Highway Research Program (SHRP) began development of the Superpave (Superior Performing Asphalt Pavements) mix design system. This system introduced improved methods to select and combine aggregates and asphalt binders based on climate and expected traffic volumes. Gyratory compaction is used to simulate compaction in the field. The fundamental difference between Superpave and the other mix design systems is that it is a performance-based system. This means that the physical properties measured in the laboratory can be directly related to field performance using engineering principles (Asphalt Institute, 1995). Rutting resistance of the asphalt mixture is controlled through the selection of high quality aggregates and asphalt binders whose performance characteristics are verified by a series of performance-based laboratory tests. No simple test procedure is used to measure mixture stability in this mix design system.

Despite the advancement of mix design technology over the last century, the rutting problem still remains (Huber, 1999). Change in the transportation industry has been rapid, and the evolution of the knowledge and tools necessary to address the changes have lagged behind (Kim et al., 1991). Traditional asphalt mix design systems such as the Hveem and Marshall methods were developed over fifty years ago yet they are still in use today. These empirical methods were based primarily on simple tests for mixture stability that were correlated to in-service pavement performance to determine suitable design thresholds. Though capable of producing good performing asphalt mixtures at the time of their development, these methods do not have the flexibility to properly characterize new materials or predict performance under new loading conditions because they do not relate directly to fundamental engineering properties such as stress and strain (Vallejo, 1976; Kim et al., 1991). The ability to measure fundamental properties is becoming increasingly important as many highway agencies start using mechanistic pavement design procedures. Recent advancements in asphalt mix design technology (i.e. Superpave) have improved traditional methods, but more work is required to establish suitable test methods that can accurately measure material stress and strain. A simple strength test that can quantify the rutting resistance of different asphalt mixtures in the laboratory is also required (Kandhal et al., 1993; FHWA, 2000).

1.1.2 The Rutting Problem: Manitoba Context

There are approximately 7,250 km of asphalt-surfaced highways currently under the control of MTGS in the province (MTGS, 1998). MTGS (formerly known as Manitoba Department of Highways and Transportation) produces and places 600,000 to 800,000 tonnes of virgin and recycled asphalt mix to maintain and rehabilitate these and other deteriorated pavement sections each year. Although rutting has always been a common pavement distress locally and across Canada, it was not until the mid 1980s that rutting of asphalt pavements was identified as a major problem on Canadian highways (Palsat et al., 2000). To address the problem, the Roads and Transportation Association of Canada (RTAC) held a series of "Pavement Rutting Seminars" across the country in 1989 (Emery, 1990). The goal of these seminars was to identify the main causes of rutting and to provide feasible solutions.

At about the same time, MTGS initiated several of their own rutting studies within the province. As reported by Fisher (2000), these studies led to significant changes in the design of local asphalt mixtures. These changes included a shift towards larger maximum aggregate size, better control of VMA, higher design air voids (4.5 percent rather than 3.5 percent), increased crush count (40 to 50 percent), stiffer asphalt cements, and a restriction that limited screened fines to 50 percent of the total fines in the mixture. Since the introduction of these changes, it appears as though the rutting resistance of asphalt pavements in the province has improved (Fisher, 2000).

Despite these improvements, there is still concern over the long-term rutting performance of asphalt pavements in the province and the adequacy of current design procedures. The American Association of State Highway and Transportation Officials (AASHTO) method of structural pavement design, which is currently used by MTGS, was developed in the 1960s based on truck tire pressures of 515 kPa (75 psi). Today in North America, it is not uncommon to see tire pressures in excess of 900 kPa (130 psi) (Middleton et al., 1986; Kim and Bell, 1988; Hudson and Seeds, 1988, Button et al., 1990, Dawley et al., 1990). This increase in tire pressure means pavements are being subjected to higher stresses than originally designed for. Consequently, there is a greater chance rutting will occur. Furthermore, truck traffic volumes are rising and there is increasing pressure from the private sector to raise allowable axle loadings and gross vehicle weights, and to allow larger trucks (9-axle semis) on the highway network. There is also pressure to relax spring loading restrictions in the province, which could have an adverse affect on rutting performance.

Current mix design procedures must also be re-evaluated because of the increase in pavement loading. Although current asphalt mix design procedures (Marshall method) and established design thresholds appear adequate for now, future performance in a changing transportation environment is uncertain. Part of the problem stems from the fact that the Marshall method is empirical and relies on correlations to known field performance. Therefore, it is difficult, if not impossible, to predict rutting performance under new loading conditions. What is needed is a simple performance-based laboratory test that can identify rutting resistance by relating fundamental engineering properties such as stress and strain to actual rutting performance in the field. To address this issue, MTGS initiated a rutting study with the University of Manitoba in October 1999. The research conducted for that study forms the basis of this thesis.

1.2 Purpose and Objectives

The purpose of this research is to investigate the rutting performance of asphalt concrete pavements in Manitoba and to identify or develop a simple strength test that measures rutting resistance in the laboratory. The objectives of this research are to:

- Review relevant literature to determine the current state of knowledge;
- Assess the rutting performance of different of in-service asphalt pavements;

- Characterize the physical properties of the asphalt pavements at the time of construction and in their present condition;
- Identify the causes of rutting in these pavements;
- Identify a simple strength test protocol that can be used to assess rutting resistance in the laboratory;
- Evaluate the strength and performance of the asphalt pavements in the laboratory using this test;
- Relate observed field performance to physical mixture properties and strength parameters;
- Establish threshold strength values and guidelines for acceptable field performance; and
- Assess the suitability of the selected test procedure for evaluation of rutting resistance of asphalt mixtures.

1.3 Scope

The scope of this study is limited to ten in-service, thick or overlaid asphalt pavement sections scattered across the province of Manitoba. Rutting of each pavement section was confined to the surface asphalt layer (mixture rutting), and as such, no investigation was done on the underlying pavement structure. The findings reported herein are based solely on the evaluation of these pavement sections.

1.4 Significance of the Research

Although considerable research has been conducted on rutting, rutting still remains a significant problem. The development of Superpave has improved the way asphalt mixtures are designed, but Manitoba and many other agencies still rely on traditional empirical mix design systems such as the Marshall method. Moreover, there is a general consensus in the industry that a simple performance test relating fundamental engineering properties to rutting performance in the field is required. Clearly the contribution of this research to MTGS and the asphalt industry as a whole is timely and will provide valuable information that will aid in the design of rut resistant asphalt mixtures.

1.5 Organization of the Thesis

The thesis is divided into six chapters. This chapter describes the basis for the research and outlines the purpose, main objectives, scope, and significance of the research. The remaining chapters are structured as follows:

Chapter 2: *Review of Rutting*

This chapter provides background information on asphalt pavement rutting that is relevant to this research. The chapter describes the different types of rutting and the mechanism by which rutting occurs. It also describes the influence of various material properties on rutting resistance.

Chapter 3: *Review of Laboratory Test Methods to Evaluate Rutting*

Chapter 3 provides a literature review of common laboratory test methods used to evaluate the rutting resistance of asphalt mixtures. Based on this review, a test procedure for this study is selected. This chapter also outlines the theory behind the test chosen for this research project.

Chapter 4: *Research Program*

Chapter 4 details the data collection and laboratory testing procedures conducted as part of this research. The general research framework is summarized including the selection of pavement test sections, the extraction of pavement cores, and the collection of pavement, traffic, and rut depth information. This chapter also details the laboratory testing performed on the extracted core samples and presents the test results.

Chapter 5: *Analysis and Discussion*

This chapter describes the procedures used to analyze the data and discusses the significant findings. Correlations between physical mixture properties, strength properties, and rutting performance are presented and discussed.

Chapter 6: *Summary, Conclusions, and Recommendations*

Chapter 6 summarizes the research work and provides insight on the important lessons learned. Recommendations for future work are given.

References and appendices are included at the end of the thesis.